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FINAL REPORT
FOR
EFFECTIVE RADIO CROSS-SECTION ANALYSIS
FROM EXPERIMENTAL MEASUREMENTS, ECHO I

21 June 1965 - 28 April 1967

Contract No.: NAS5 - 9648

Prepared by
Collins Radio Company
Cedar Rapids, Iowa

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ABSTRACT

This report describes the reduction to satellite effective radio cross section of the reflected radio signal power measurements which were made on the Echo I passive satellite by the Collins Radio Company. The measurements were made bistatically between Cedar Rapids, Iowa, and Richardson, Texas (1100 km terminal separation), at 810 and 960 MHz, and monostatically from Cedar Rapids, Iowa, at 810 MHz. The data reduced were taken from measurements at 810 MHz and consisted of 24 satellite passes covering the period from launch in August 1960 to April 1963, with a large portion of the data concentrated in the first month from launch. The cross-section mean and median, density histogram and distribution function are presented for each pass; and the data reduction techniques are described.

Conclusions drawn from these data showed that the averaged mean effective radio cross section for Echo I within the first month after launch was about 3 db below the theoretical cross section of 729.64 square meters (or 28.63 db relative to one square meter). A gradual diminution of the cross section took place over the three years of life which were examined, finally becoming 6 db less than the theoretical cross section. During the first month after launch the 10 to 90 percent fading range was, typically, 2 to 4 db and gradually changed to, typically, 6 to 8 db near the end of three years of life. A comparison of Echo I measured at 810 MHz with Echo II measured at 2.3 GHz during their first years of life shows that the Echo I effective radio cross section was 3 db less than theoretical while Echo II was only 1.0 db less than theoretical. The fading range (10 to 90 percent) also differed in the first year life period; typically, 2 to 4 db for Echo I and 13 db for Echo II. The gradual trends in fading over the three-year period made the Echo I passive satellite appear more similar to Echo II fading.

Signal scintillations encountered during communications utilizing Echo I do not require corrective measures uncommon to design practices used in other systems. Fading may be effectively treated with diversity techniques.

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SECTION 1

INTRODUCTION

The NASA Echo I passive satellite was placed in orbit on 12 August 1960. The reflectivity of the vapor deposited aluminum on the Mylar plastic skin was better than 98 percent at uhf radio frequencies. Initially the satellite orbited about 1600 kilometers (1,000 statute miles) above the surface of the earth at an inclination of 47 degrees to the equator and with an anomalistic period of 118 minutes. Initially the satellite remained sunlit throughout all of its orbit. In a little less than 2 weeks, the satellite passed through the shadow of the earth and was first observed making this transition on August 25 during pass number 156 both optically and by radio. Pressurization, achieved initially with sublimating chemicals, was presumed to have been lost within the first week.

Atmospheric drag encountered by the satellite was much less than anticipated and estimates of satellite lifetime have had to be greatly extended.

Measurements were performed by Collins Radio Company over a period from date of launch to the latter part of 1963. Experimental data on the basic transmission loss, temporal variations in transmission loss, and bandwidth of the transmission media and communication capacity were obtained. A portion of the data was obtained by bistatic operation using two terminals, one at Richardson, Texas (near Dallas), and the other near Cedar Rapids, Iowa. The remainder of the data was obtained by monostatic operation from the Cedar Rapids terminal operated in a time sharing mode. Results from these data have been presented in Company reports.^{1 2}

This report contains statistically reduced data. Measurements of radio signal intensity are interpreted in terms of the effective radio cross section of the satellite. The mean, the median, the upper and the lower deviation and the skewness (the ratio of the upper and the lower deviation) are obtained for the cross section. The cross-section density histogram and the cross-section distribution function are also shown. These data were obtained from measurements made during the period from August 1960 through April 1963. Twenty-four passes were analyzed, fifteen of them occurring in the first month after launch.

SECTION 2

EXPERIMENTAL EQUIPMENT

The experimental equipment used to perform the measurements of signal intensity included a high-powered uhf transmitter, a phase-lock receiver with a parametric amplifier, and high-gain tracking antennas. Bistatic operation included terminals at Dallas, Texas, and Cedar Rapids, Iowa. Special purpose modulation was employed for bandwidth measurement as well as for communication modes. Monostatic operations were performed at the Cedar Rapids, Iowa, terminal by means of time sharing (50 percent duty cycle). Performance parameters for the system are as follows:

Terminal separation: 1,100 km (700 statute miles).

Slant range distance to satellite: 3,000 to 10,000 km.

Basic transmission loss between ground terminals: 260 to 280 db (assuming a perfect 100-foot diameter metal sphere).

Frequency: 810 MHz (Dallas to Cedar Rapids).

Dallas, Texas, Terminal

Transmitter power: 40 dbw (10 kw).

Receiver sensitivity with parametric amplifier (955 MHz)

(Phase-lock threshold): 190 dbw.

Antenna gains: $G_T = 35$ db (transmit); $G_R = 39.5$ db (receive).

Cedar Rapids, Iowa, Terminal

Transmitter power: 40 dbw (10 kw).

Receiver sensitivity with parametric amplifier (810 MHz)

(Phase-lock threshold): 190 dbw.

Antenna gains: $G_T = 34$ db (transmit); $G_R = 30.5$ db (receive).

Signal intensity data analyzed in this report were obtained from the receiver at Cedar Rapids, Iowa (operating at 810 MHz). Detailed descriptions of the equipments are contained in Collins Radio Company reports.

A simplified block diagram of the radio receiver is shown in figure 1. Signal amplitude data was obtained from the receiver in two outputs, agc and amplitude detector. These

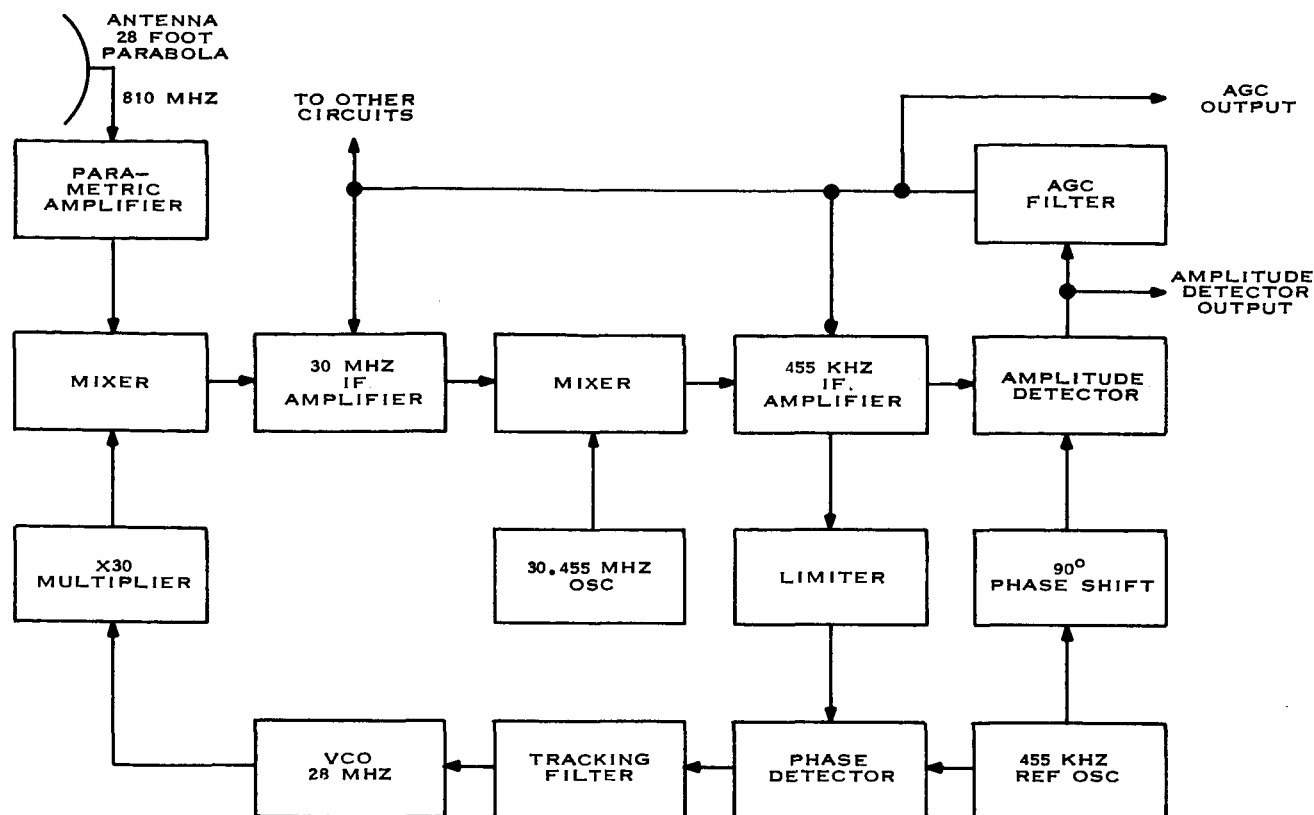
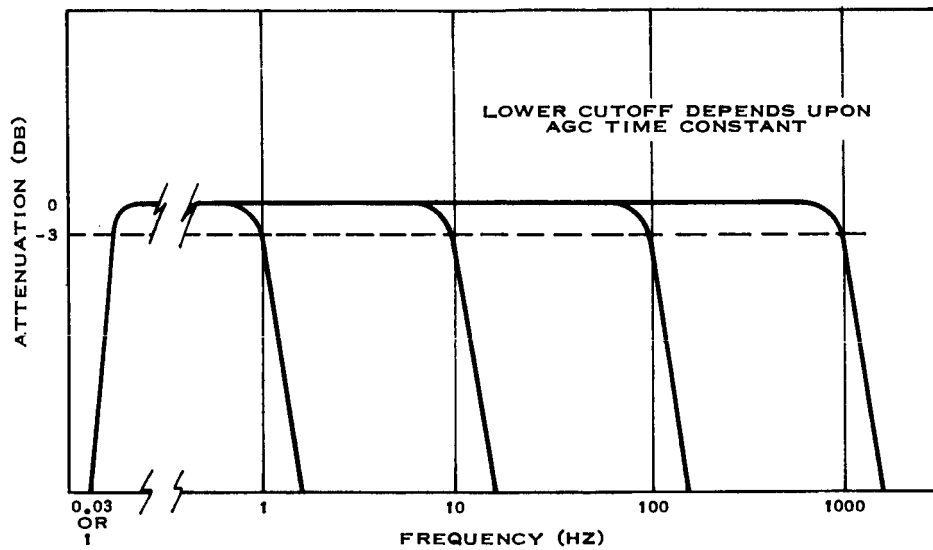


Figure 1. Receiver at Cedar Rapids, Iowa, Simplified Block Diagram

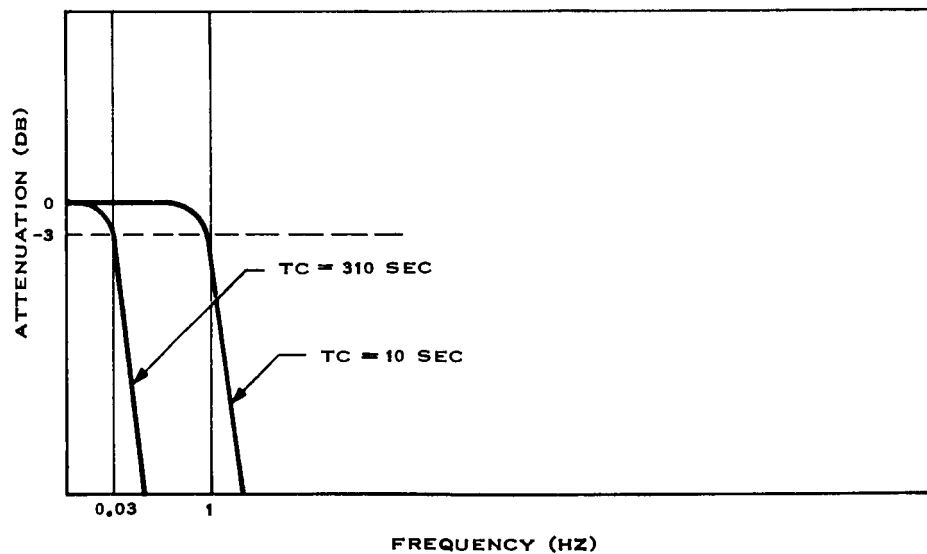
outputs follow and precede, respectively, the agc filter. Their responses are indicated in figure 2. Reconstruction of the signal at the input of the receiver was obtained by suitably combining these two outputs. These and other outputs were recorded on magnetic tape.

The use of the phase-lock receiving equipment was partly dictated because of the weak signal powers expected. The detection bandwidth for the system is 2 kHz. Post detection filtering was used in the amplitude detector output in order to recover signals near threshold.

Other data obtained by measurement which were pertinent to the signal conditions were doppler, azimuth, and elevation position.



(A) RESPONSES OF THE AMPLITUDE DETECTOR
ISO-AMPL OUTPUT OF THE RECEIVER



(B) RESPONSES OF THE AGC OUTPUT
OF THE RECEIVER

Figure 2. Typical AGC and Amplitude Detector Responses

CROSS-SECTION MEASUREMENT

The effective radio cross section of a passive satellite is defined as the area that intercepts and reflects electromagnetic energy which is projected onto a plane perpendicular to the direction of the incident wave. This definition applies when the diameter of the satellite is much greater than the wave length of the electromagnetic energy. The ratio d/λ for the system used to provide the measurements was approximately 100. Measurement of the satellite cross section was affected by the shape of the satellite, the operating parameters of the tracking stations, and the satellite position with respect to the tracking stations. The effects that resulted from the operating parameters were removed from the data and the behavior of the satellite cross section was studied.

3.1 EFFECTIVE RADIO CROSS SECTION.

The effective radio cross section, σ , of a passive Echo-type satellite has been defined previously. For derivation of the expression for the satellite's effective cross section, consider the bistatic configuration involving a transmitter, satellite, and receiver as shown in figure 3. The power density, P_S , at the satellite distance, d_1 (meters), from the transmitter with output power, W_T , and antenna gain G_T is

$$P_S = \frac{W_T G_T}{4\pi d_1^2} \quad (1)$$

If the wavelength of the energy transmitted is much less than the diameter of the satellite, the total power received is the power density times the effective satellite cross-sectional area, σ . For a perfectly conducting metallic sphere, the reradiated power is equal to the received power; and the power is radiated isotropically. Thus, the power density at the receiver due to power reflected from the satellite is

$$P_R = \frac{W_T G_T}{4\pi d_1^2} \frac{\sigma}{4\pi d_2^2} \quad (2)$$

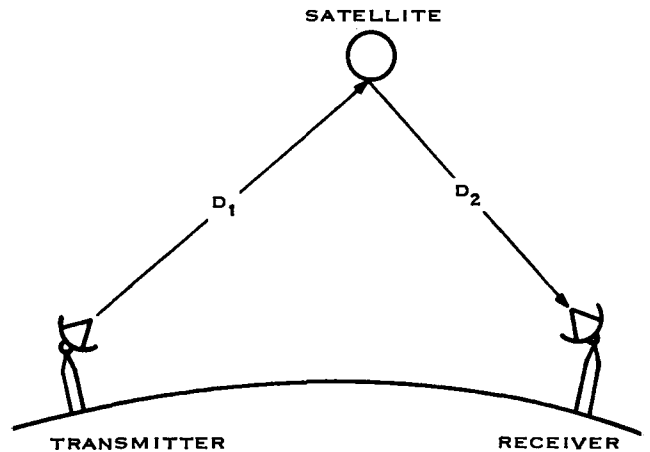


Figure 3. Passive Satellite Communication Circuit Configuration

where d_2 is the distance (meters) from the satellite to the receiver. The total received power (W_R)

$$W_R = \frac{W_T G_T}{4\pi d_1^2} \frac{\sigma}{4\pi d_2^2} \frac{\lambda^2 G_R}{4\pi} \quad (3)$$

where G_R is the receiving antenna gain, λ is the wavelength (in meters), and $\frac{\lambda^2 G_R}{4\pi}$ is the antenna effective aperture. Solving this equation for the effective cross section, σ , gives

$$\sigma = \frac{(4\pi)^3 (d_1 d_2)^2}{G_T G_R \lambda^2} \frac{W_R}{W_T} \quad (4)$$

If a cross section of unit size (1 square meter) is chosen as the basis of comparison, the cross section can be expressed relative to 1 square meter cross section as follows:

$$10 \log \frac{W_R(\text{actual})}{W_R(1 \text{ m}^2)} = 10 \log \frac{\text{Area (effective)}}{\text{Area (1 m}^2\text{)}} \quad (5)$$

or cross section in db relative to 1 square meter.

3.2 SOURCES OF DATA.

The preceding paragraph indicates the quantities required to determine the effective satellite radio cross section from the experimental configuration shown in figure 3. The required information consists of the transmitted and received power data, the satellite range data, and the system parameters. The system parameters were measured prior to the experiment and did not change in an uncontrolled manner. The numerical values of the various system parameters are given in section 2.

Data on the satellite position with respect to the tracking stations were obtained from post facto orbit analysis of information from photographic records and were provided by the Smithsonian Institute, Astrophysical Observatory. The azimuth, elevation, and range values were furnished in tabular form at 30-second intervals.

The received power level data were recorded on magnetic tape from the tracking receiver outputs. The agc and amplitude detector outputs were recorded separately and then combined to yield the composite signal. The data were recorded by FM on magnetic tape at 1-7/8 inches per second with a bandwidth of 312 Hz.

THE DATA REDUCTION PROGRAM

In order to study the radio behavior of the Echo I satellite, the data were reduced in terms of the satellite cross section. By doing this, the behavior of the satellite was made independent of the data gathering configuration. Thus, the description of the satellite cross section can be used in the design of communication systems using the Echo I type satellites.

The effective radio cross section is expressed in terms of square meters. The theoretical cross section for the Echo I satellite is 729.64 square meters. As is convenient for system design calculations, the satellite cross section is also expressed in terms of decibels with respect to one square meter. This convention for a passive satellite arises because the effective radio cross section is proportional to the power reflected by the satellite. The theoretical cross section is 28.63 db relative to one square meter.

4.1 ANALOG DATA PROCESSING.

A functional diagram of the analog portions of the data reduction to satellite cross section is shown in figure 4. The received power level data was in the form of separately recorded agc and amplitude detection receiver outputs. By the use of receiver calibration information, the agc and amplitude detector data were linearized in terms of appropriately scaled logarithmic functions and were added to give the power level data in a form linear in dbm. A strip chart of the raw data from Pass No. 34 is shown in figure 5. A strip chart for the same data after combination of the agc and amplitude detector is shown in figure 6. Since the effective cross-sectional area is proportional to received power, the data were linearized in terms of power. The data were then low-pass filtered to remove tape and

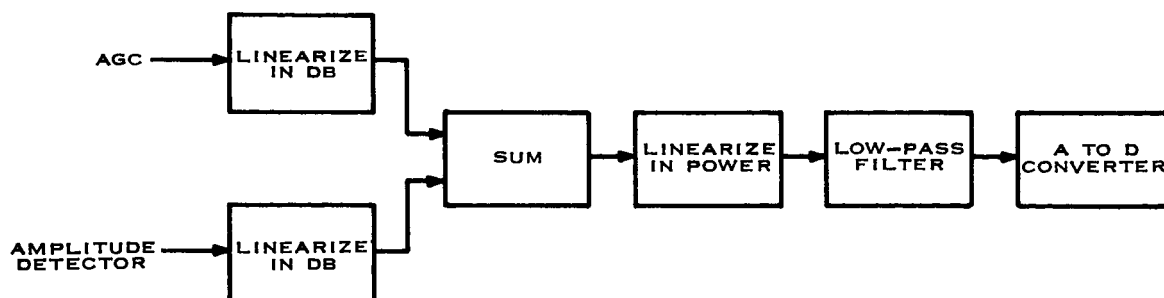


Figure 4. Analog Data Processing

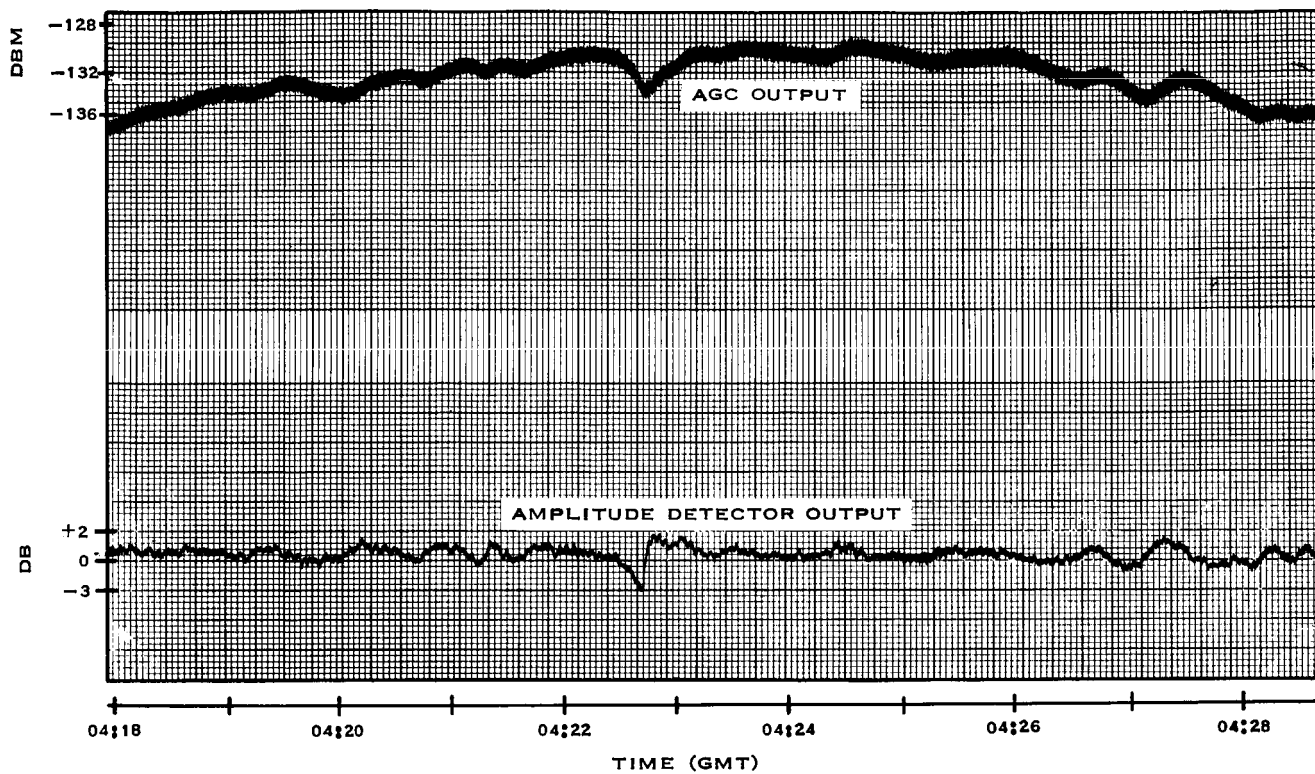


Figure 5. Raw Data for Pass 34

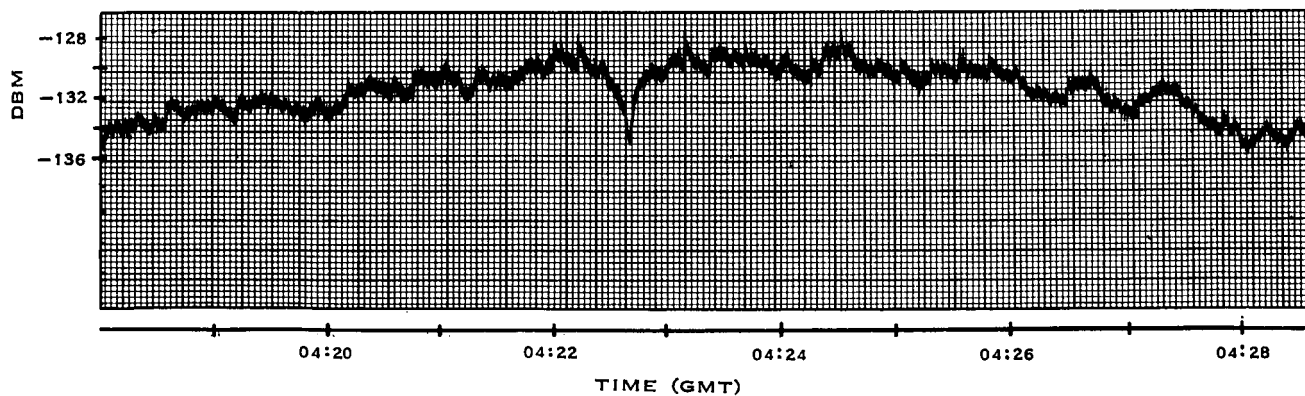


Figure 6. Data for Pass 34 After Combination of AGC and Amplitude Detector Signals Shown in Figure 5

system noise and converted to digital form for computer processing. The analog-to-digital conversion sampling rate was five samples/second. Digital values were correct to four decimal digits. The low-pass filter has a 3-db cutoff frequency of 3.6 Hz and an attenuation rate of 12 db/octave.

The monostatic data contained the 50- to 100-Hz radar pulsing signal. A 5-pole Butterworth low-pass filter with a 12-Hz, 3-db cutoff frequency was used on the amplitude detector data to remove the pulsing signal prior to combination with the agc data.

4.2 DIGITAL DATA PROCESSING.

The effective cross-sectional area was computed using an IBM 7074 digital computer from the digital power level data, range data, and system parameters as described in section 2. A linear interpolation was performed on the 30-second range data values to obtain 1/5-second values to match the 1/5-second power level samples. The computation yielded values of satellite cross section every 1/5 second. A flow diagram of the computer program is shown in figure 7.

The statistics of the effective cross section as described in paragraph 4.3 were computed from the five per second values. A flow diagram of the statistics program is shown in figure 8.

4.3 STATISTICAL REPRESENTATIONS OF THE DATA.

4.3.1 Probability Density Histogram

The probability density histogram of a variable is a measure of the probability that the magnitude of the variable will lie in a certain magnitude interval. As a measured quantity, it represents the fraction of time that the variable spends in the magnitude interval. The possible range, L , of instantaneous cross-section variation is divided into a number, K , of equal intervals. The width of each interval is then L/K .

There are N total cross-section values, $N \gg K$; the estimate of the probability P_i that the instantaneous cross section will have a value in the interval i , $1 \leq i \leq K$, is given by

$$P_i = \frac{n_i}{N}$$

where n_i is the total number of discrete cross-section values falling within the i^{th} interval. The histogram is a plot of the values of P_i versus the variable amplitude. Figure 9 shows the time variation of a variable and the associated probability density histogram.

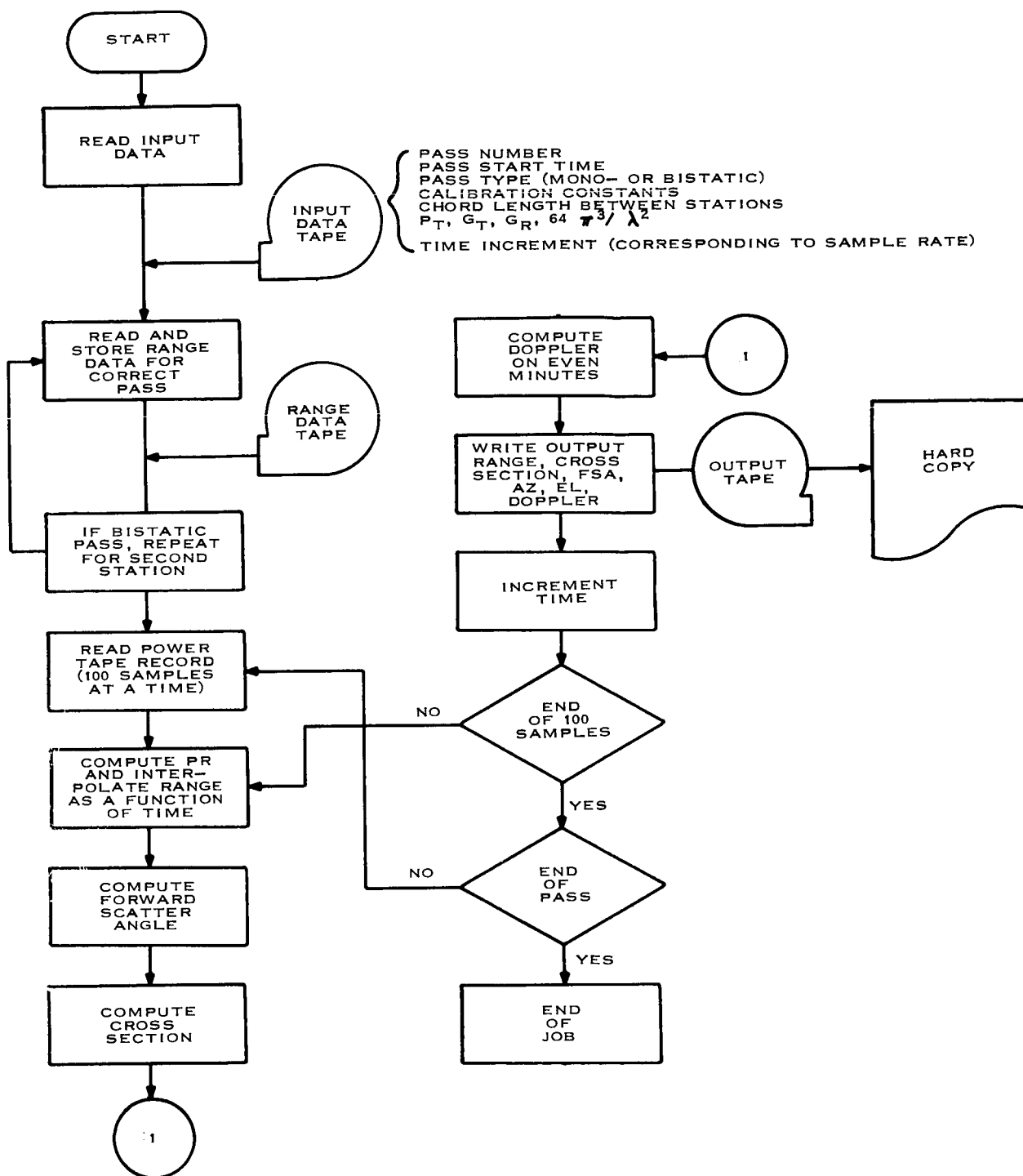


Figure 7. Main Cross-Section Program, Operation Flow Diagram

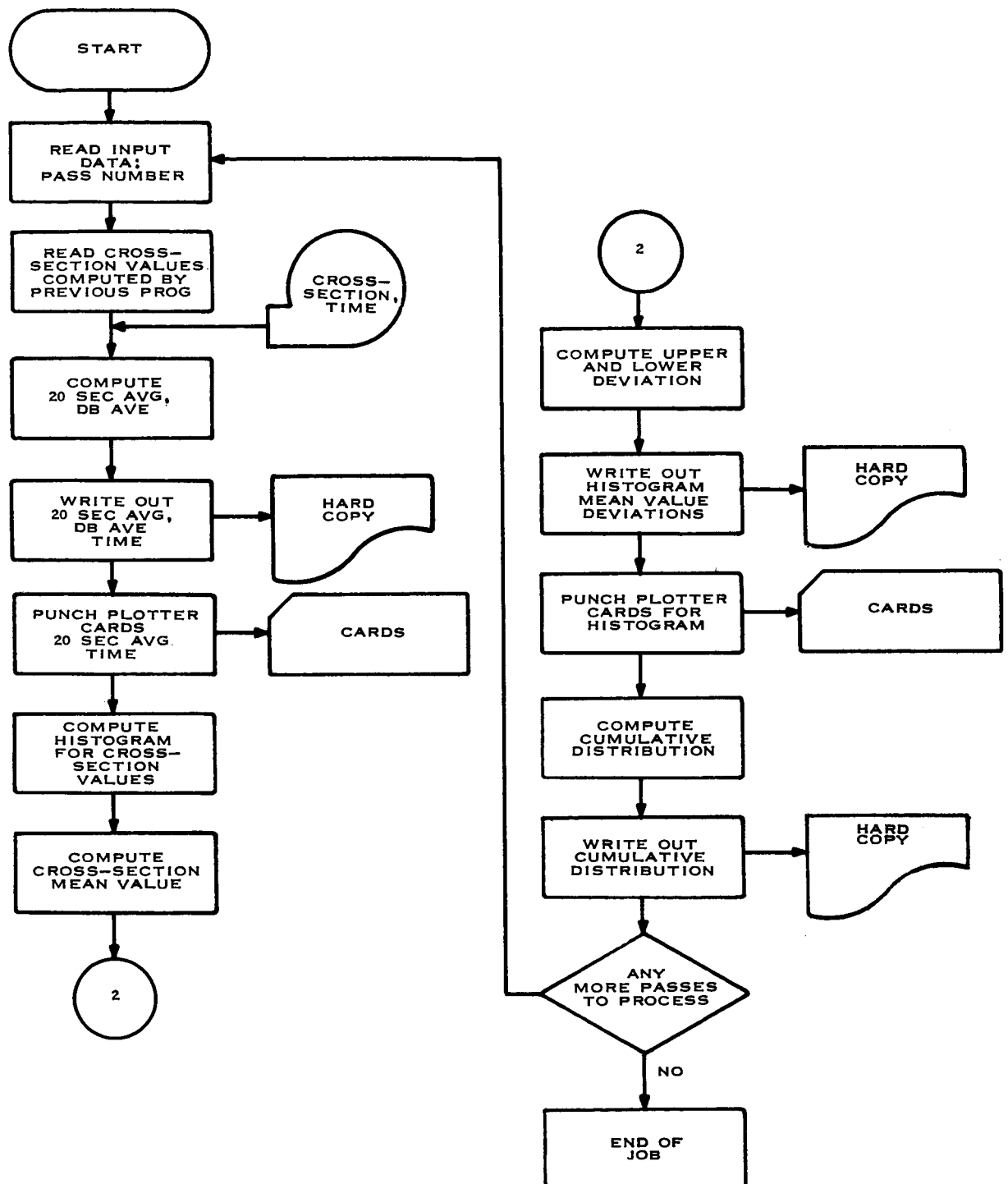


Figure 8. Statistics Program

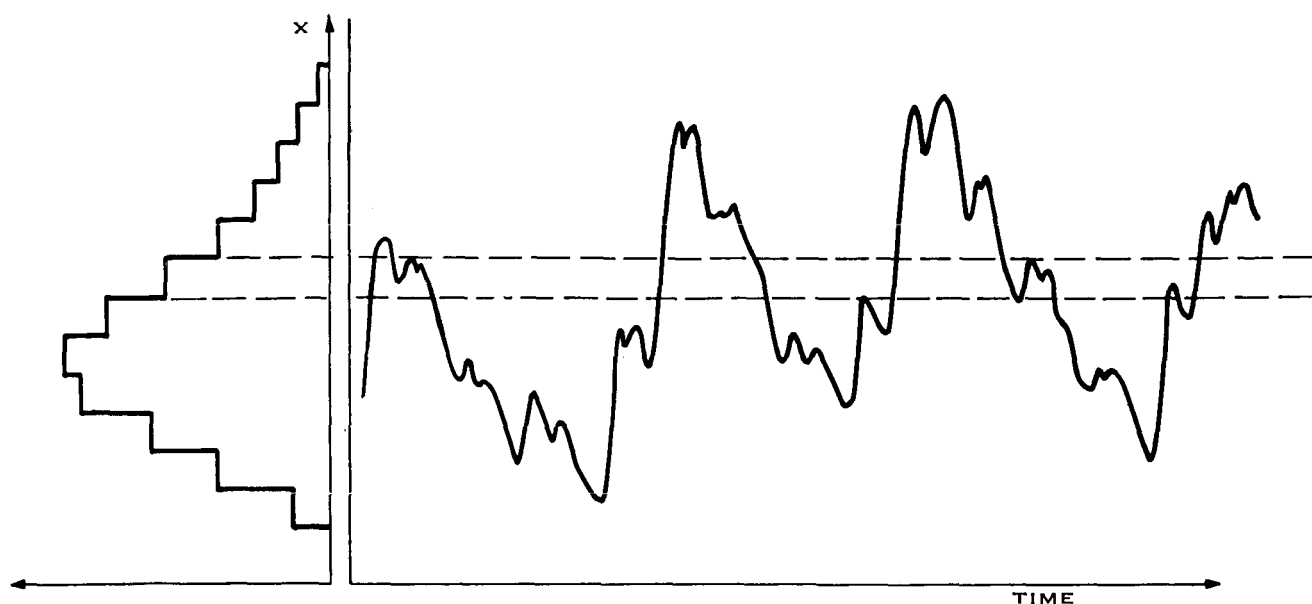


Figure 9. Probability Density Histogram for the Variable X

4.3.2 Probability Distribution Function

The cross-section distribution is the representation of the probability that the instantaneous cross section will be greater than a given value. Since the instantaneous cross section can have only one value at any given time, the histogram interval values associated with σ are mutually exclusive. Therefore, the probability that the cross section (σ) will be greater than a given value (σ_0) is given by the sum of the histogram probability values for the intervals of $\sigma > \sigma_0$. Thus, if the histogram contains K intervals and σ_0 lies in interval ℓ , $1 \leq \ell \leq K$, the probability that $\sigma > \sigma_0$ is

$$P(\sigma > \sigma_0) = \sum_{i=\ell}^K P_i$$

where P_i is the probability value for the i^{th} interval. An example of a probability distribution function as derived from the histogram of figure 9 is shown in figure 10.

Due to the fact that Rayleigh amplitude statistics occur frequently in the investigation of radio wave propagation, a special graph paper has been designed to facilitate the plotting of the Rayleigh probability distribution function. On the Rayleigh paper, a Rayleigh distribution function plots as a straight line. This paper will be used to present the results in section 4.

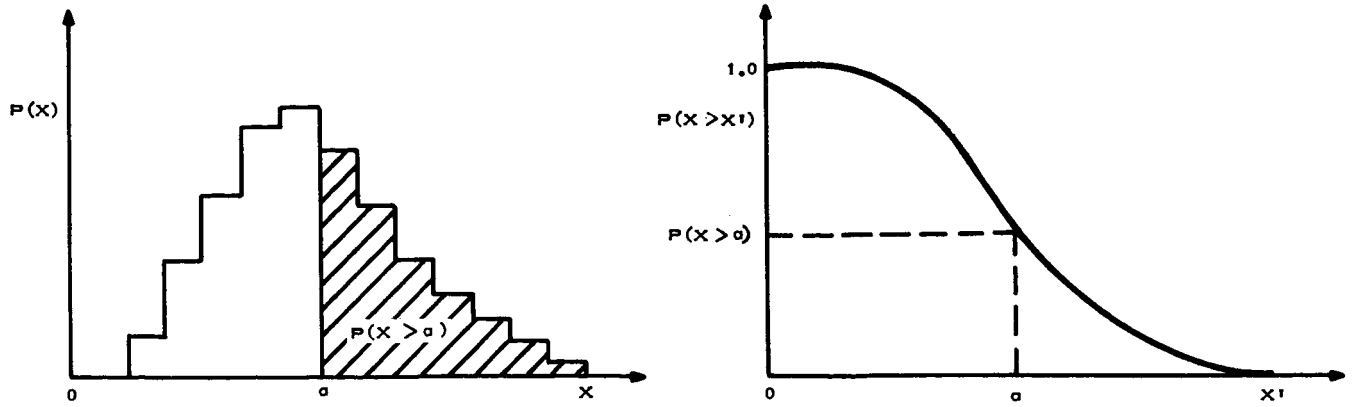


Figure 10. Probability Distribution Function of X
as Derived from the Histogram

4.3.3 Mean Cross Section

The mean cross section is the arithmetical average of the instantaneous cross section. For data in discrete form, the mean is the sum of the cross-section values divided by the total number of values. The mean is directly calculated from the cross-section density histogram. The probability value, P_i , for an interval, i , of the histogram is given by the ratio of the number of cross-section values falling within the interval to the total number of values, N . The product $P_i \sigma_i$ then represents the sum of the cross-section values falling within interval i divided by N . The sum of all cross-section values is the sum of $P_i \sigma_i$ over all intervals. Thus, the mean cross section $\bar{\sigma}$ is

$$\bar{\sigma} = \sum_{i=1}^K P_i \sigma_i = \frac{1}{N} \sum_{i=1}^K n_i \sigma_i$$

where K is the total number of intervals, N is the total number of data points, and n_i is the number of data points in the i^{th} interval.

4.3.4 Median Cross Section

The median cross section is that value for which the cross section has equal probability of being above or below. This is the value for which the cross-section distribution is equal to 0.50, or the value that is exceeded one-half the time by the instantaneous cross section.

4.3.5 Cross-Section Skewness

A measure of the skewness of the cross section about the mean cross section is provided by the ratio of the upper rms deviation from the mean to the lower rms deviation from the mean. A value of the ratio of unity indicates that the cross section (with quadratic weighting) is symmetrically distributed about the mean value. A value less than unity tends to show that the instantaneous cross section spends more time below the mean value than above. The reverse is true for a value greater than unity.

The upper and lower rms deviations are calculated from the cross-section density histogram. If the mean cross section $\bar{\sigma}$ falls within interval ℓ of the histogram containing K intervals, then the

$$\text{Upper Deviation} = \left[\sum_{i=\ell+1}^K (\sigma_i - \bar{\sigma})^2 P_i \right]^{1/2}$$

$$\text{Lower Deviation} = \left[\sum_{i=1}^{\ell-1} (\sigma_i - \bar{\sigma})^2 P_i \right]^{1/2}$$

SECTION 5

REDUCED DATA

The reduced data are presented in this section for the 24 Echo I passes reduced. The data covers the period from 15 August 1960 to 20 April 1963. The passes are distributed historically as illustrated in figure 11. Seventeen of the 24 passes were examined from the first month after launch because loss of positive pressurization and eclipsing occurred during that time. The remaining seven passes are distributed over the remaining time. Data from 13 passes were obtained from Cedar Rapids, Iowa, and Dallas, Texas, bistatic tracking operations; and data from 11 passes were obtained from Cedar Rapids monostatic radar tracking.

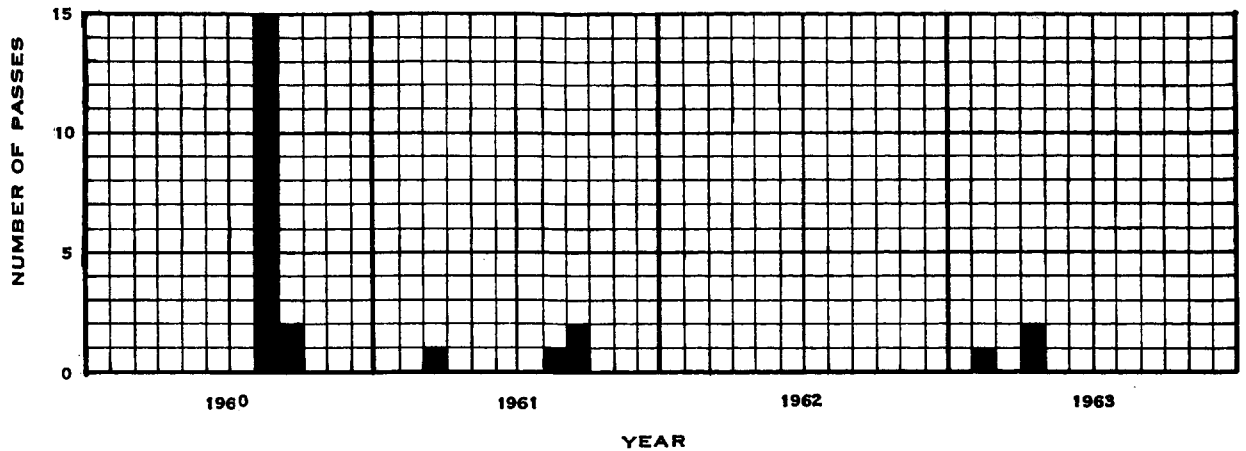


Figure 11. Historical Distribution of Reduced Data

All of the results from each pass are presented together in this section (see figures 12 through 35). Comparative analysis of the results is presented in section 6. The results presented from each pass consist of the following:

- (1) Pass number.
- (2) Pass date.
- (3) Bistatic or monostatic operation.
- (4) Mean value of cross section.
- (5) Median value of cross section.
- (6) A strip chart recording showing the raw data used (linear in received power).
- (7) A plot of 20-second averages of instantaneous cross section versus time.
- (8) Cross section density histogram.
- (9) Cross section distribution function plotted on a Rayleigh scale.

Graphs are labeled in both square meters of cross-sectional area and in decibels relative to one square meter. The periods of time that the receiver was in an out-of-lock condition are indicated by a dark bar at the top of the strip charts. These periods of data were excluded from cross-section computation.

All efforts have been made to minimize errors in the results due to processing of the data. The accuracy of the results are within ± 1 percent of the mean value per pass or approximately ± 1 db.

PASS NO. 34

PASS DATE 15 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = 359.83 M²
25.56 DB REL ONE M²

MEDIAN CROSS SECTION = 347 M²
25.4 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 119.99 M²

LOWER DEVIATION FROM MEAN = 67.863 M²

SKEWNESS = 1.78

NO. OF DATA SAMPLES = 2685

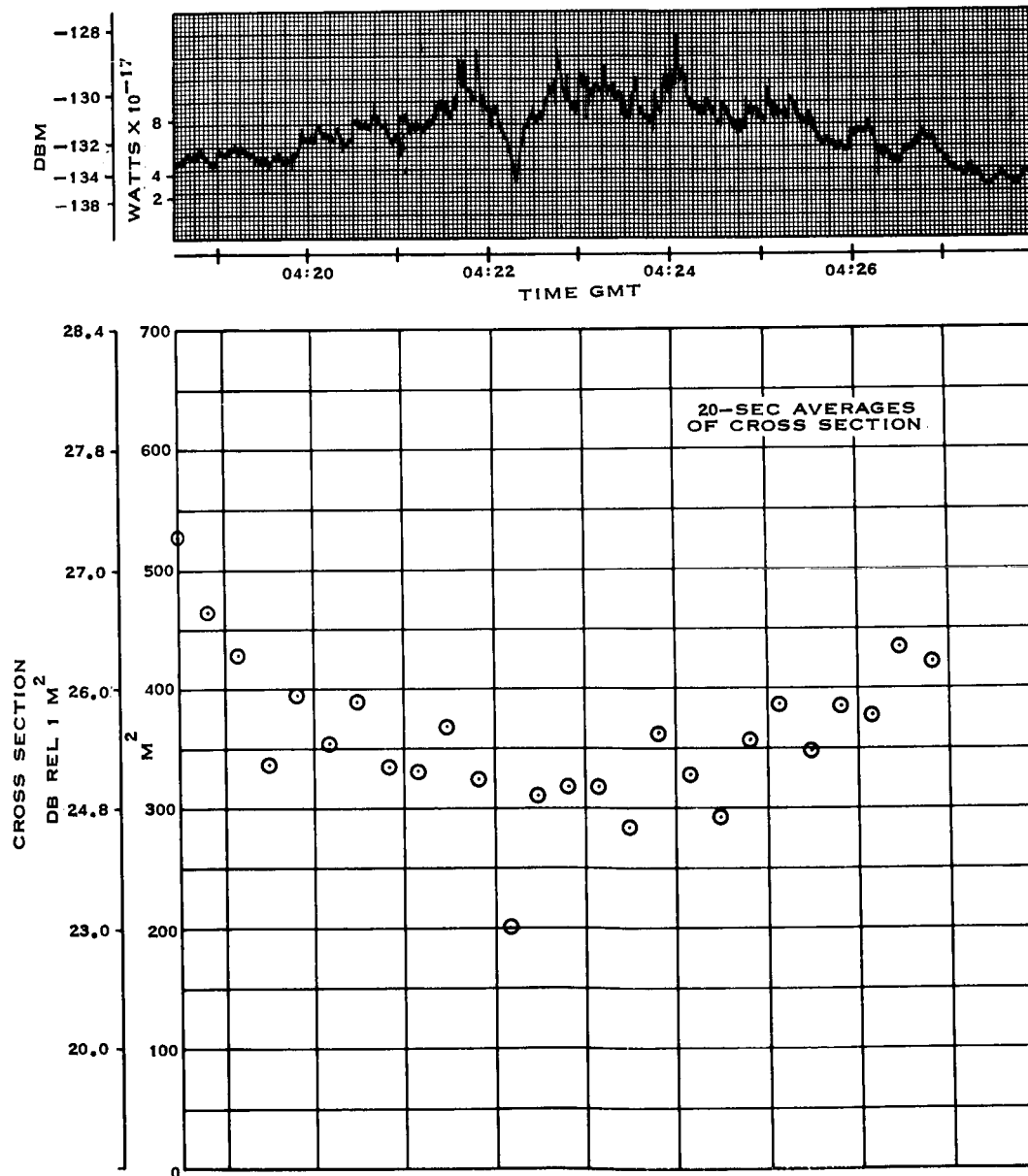


Figure 12. Pass No. 34 Data (Sheet 1 of 2)

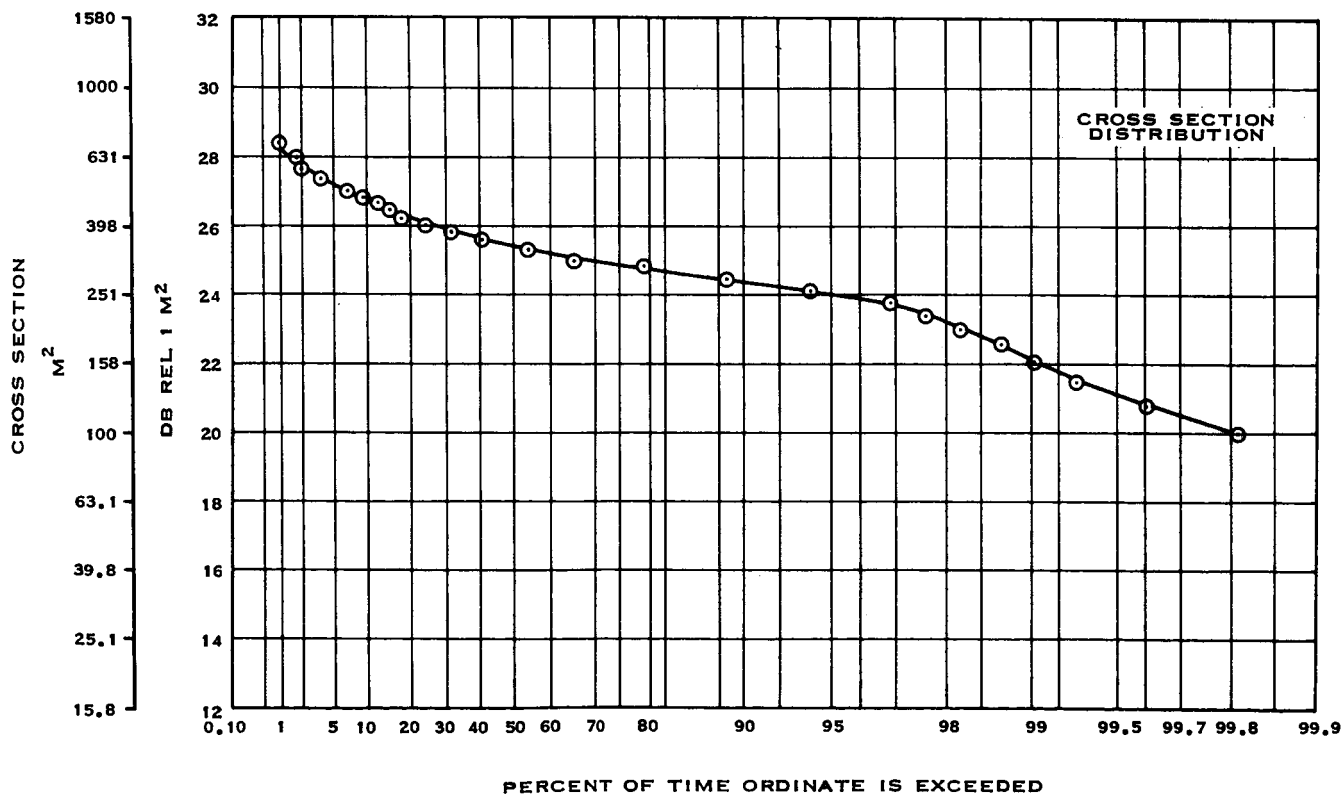
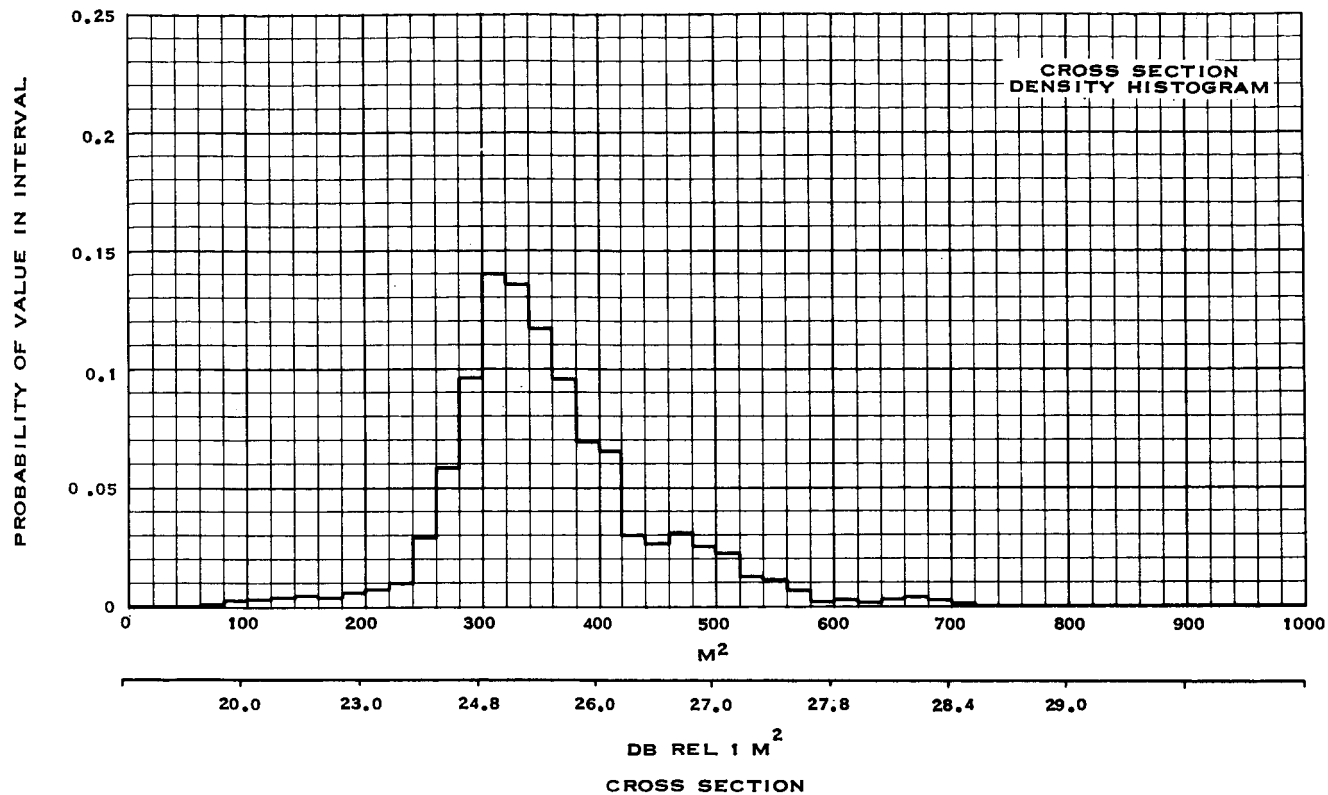


Figure 12. Pass No. 34 Data (Sheet 2 of 2)

PASS NO. 47

PASS DATE 16 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = 311.48 M^2
24.93 DB REL ONE M^2

MEDIAN CROSS SECTION = 324 M^2
25.1 DB REL ONE M^2

UPPER DEVIATION FROM MEAN = 108.08 M^2

LOWER DEVIATION FROM MEAN = 128.42 M^2

SKEWNESS = 0.84

NO. OF DATA SAMPLES = 3024

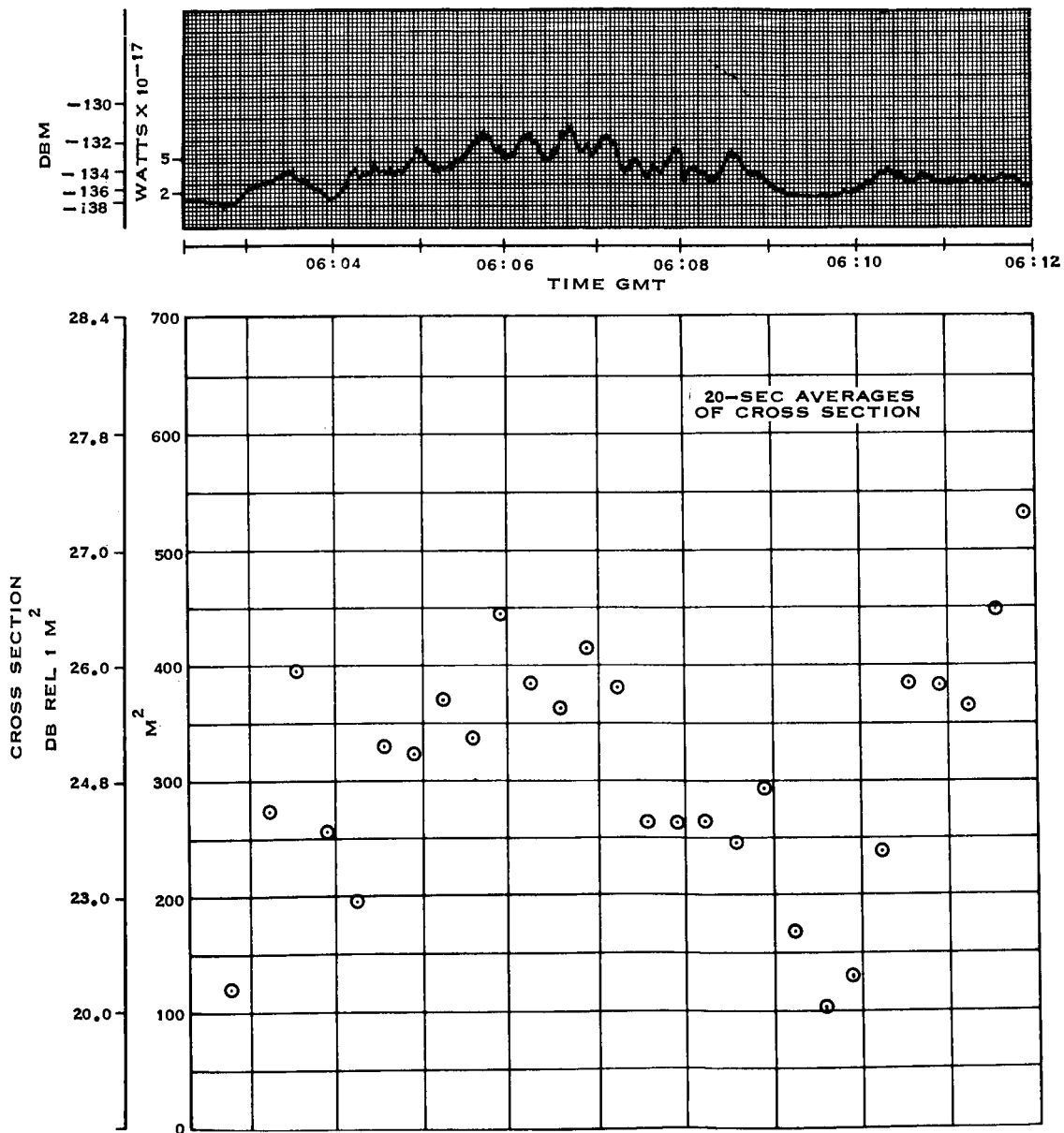


Figure 13. Pass No. 47 Data (Sheet 1 of 2)

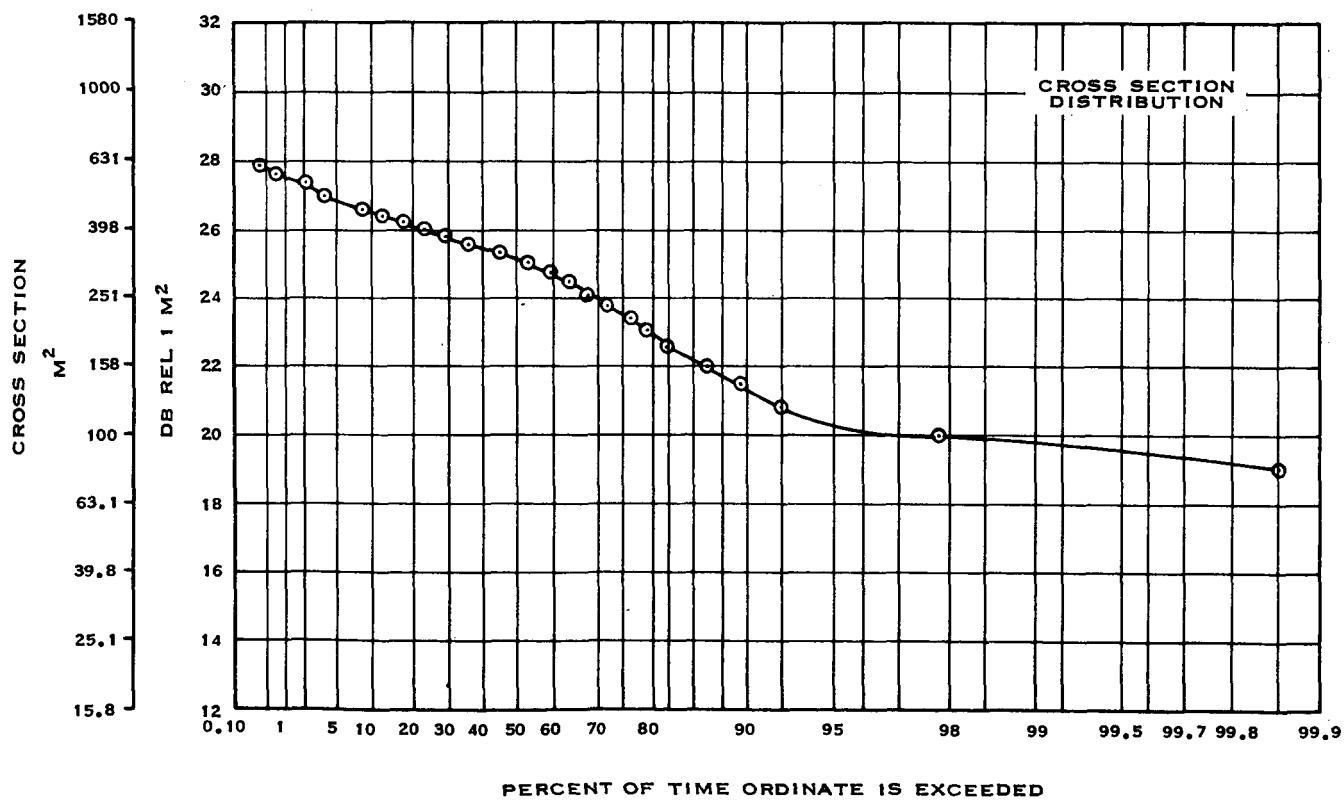
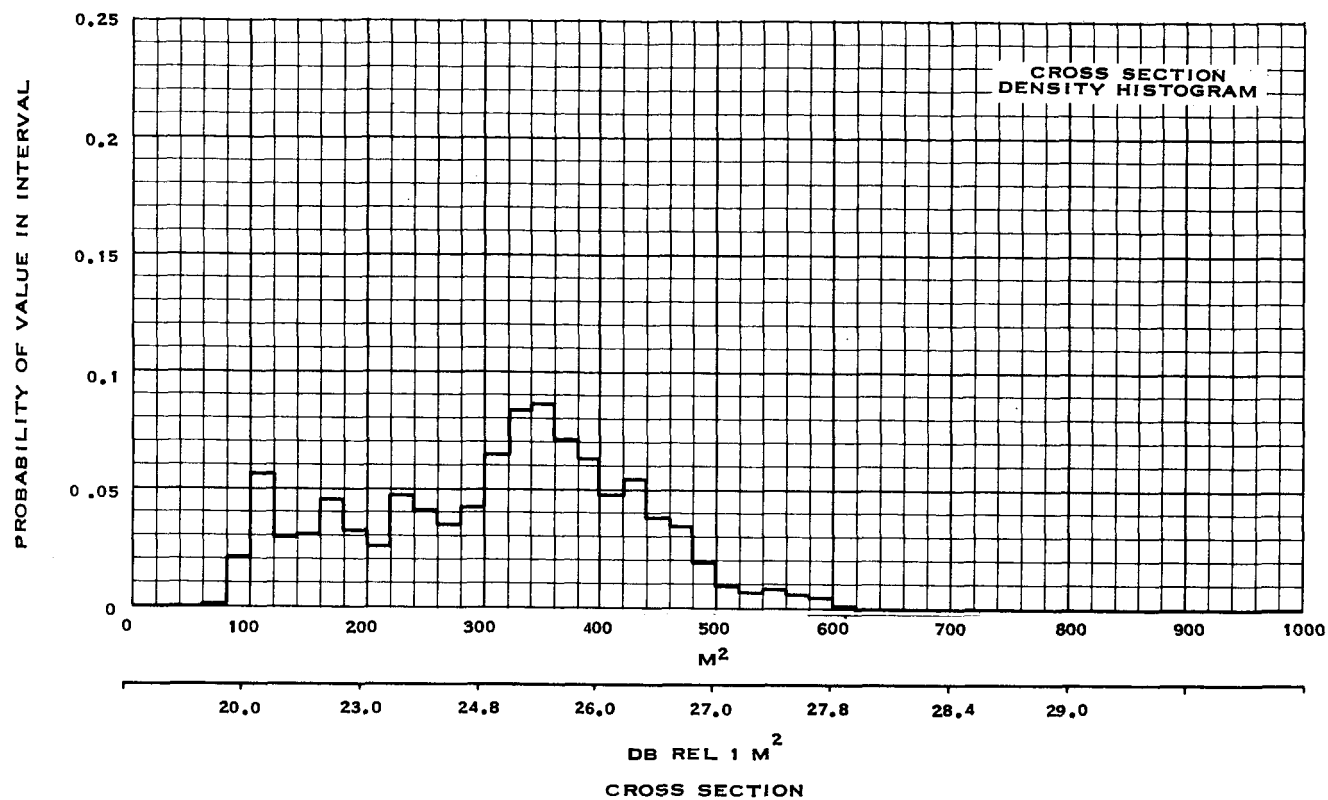


Figure 13. Pass No. 47 Data (Sheet 2 of 2)

PASS NO. 57

PASS DATE 17 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = 336.15 M²
25.26 DB REL ONE M²

MEDIAN CROSS SECTION = 363 M²
25.6 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 66,213 M²

LOWER DEVIATION FROM MEAN = 121.72 M²

SKEWNESS = 0.55

NO. OF DATA SAMPLES = 3497

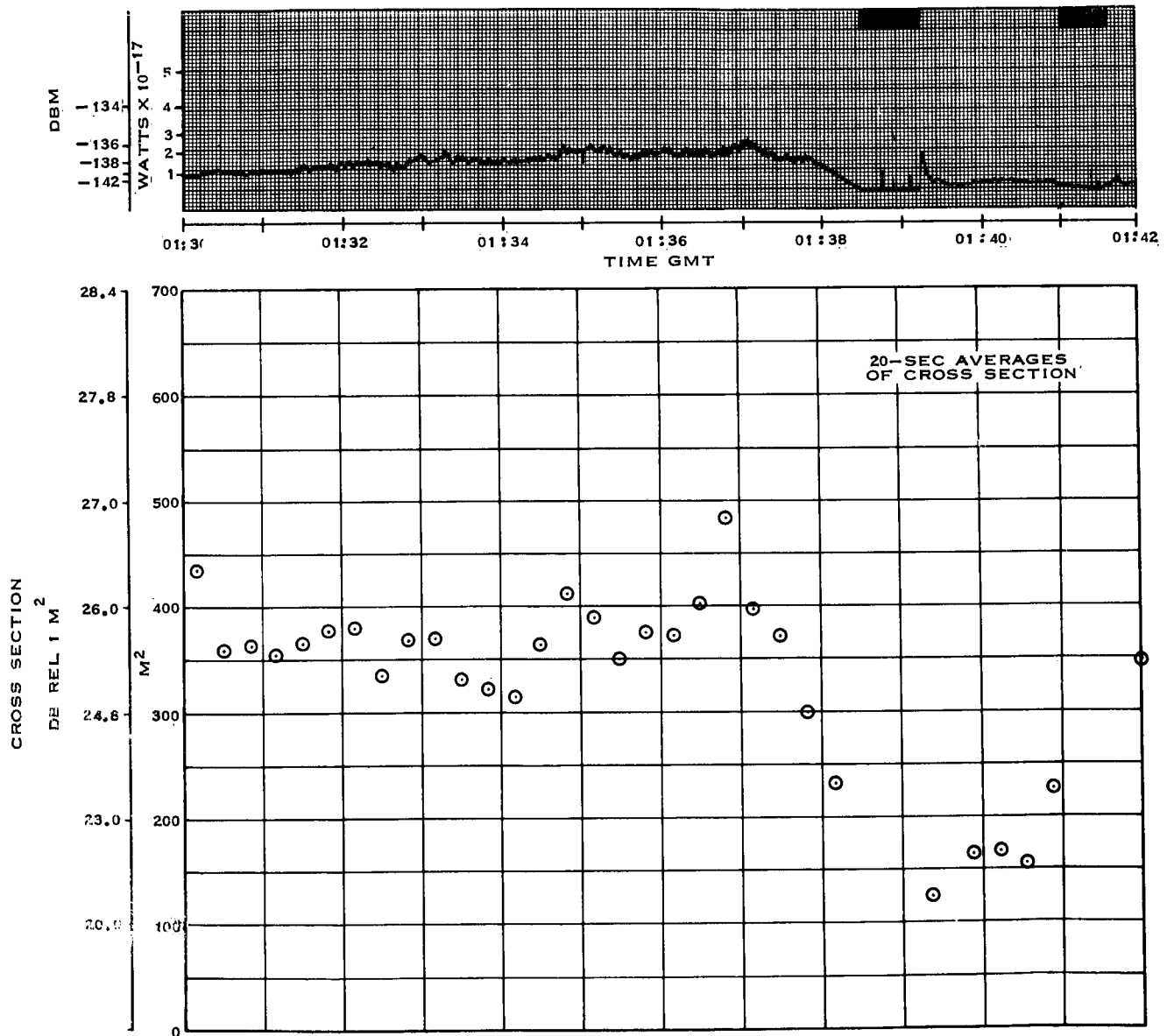


Figure 14. Pass No. 57 Data (Sheet 1 of 2)

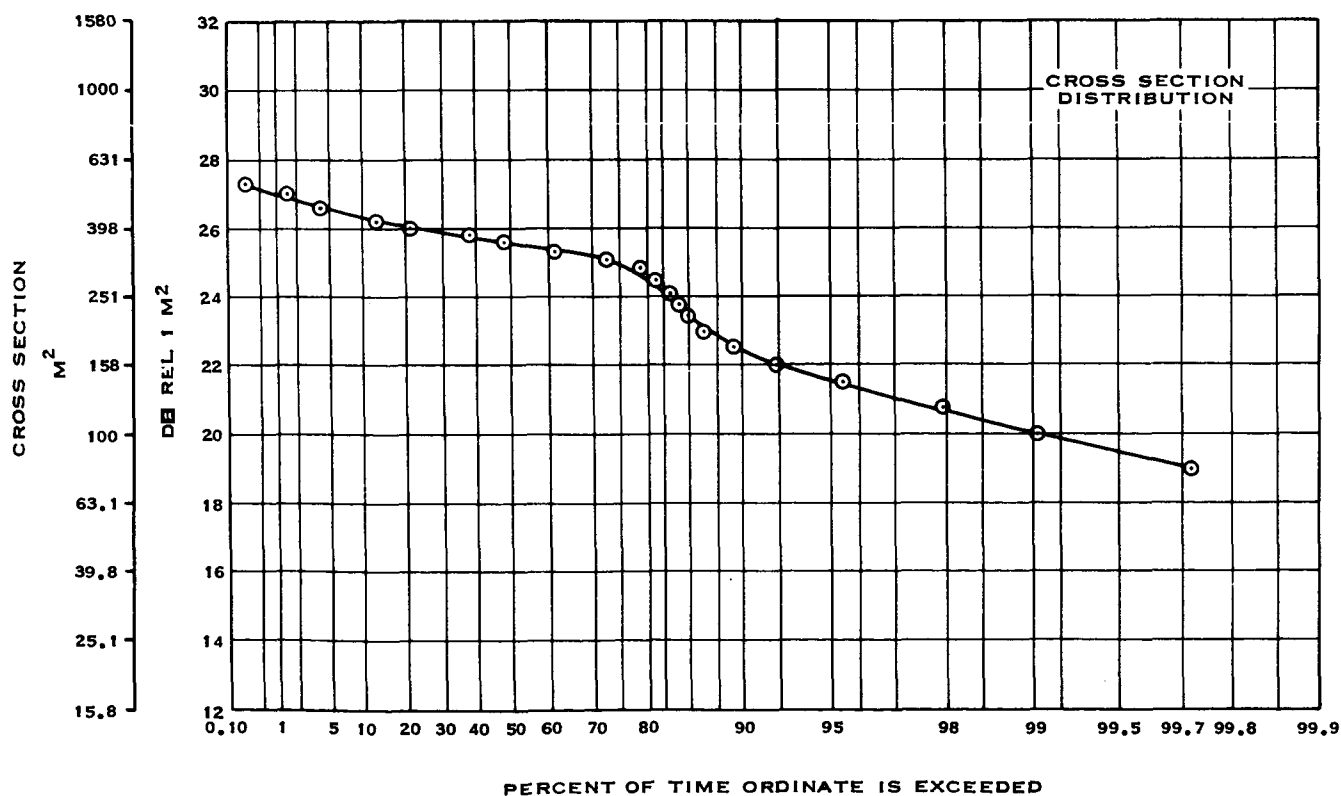
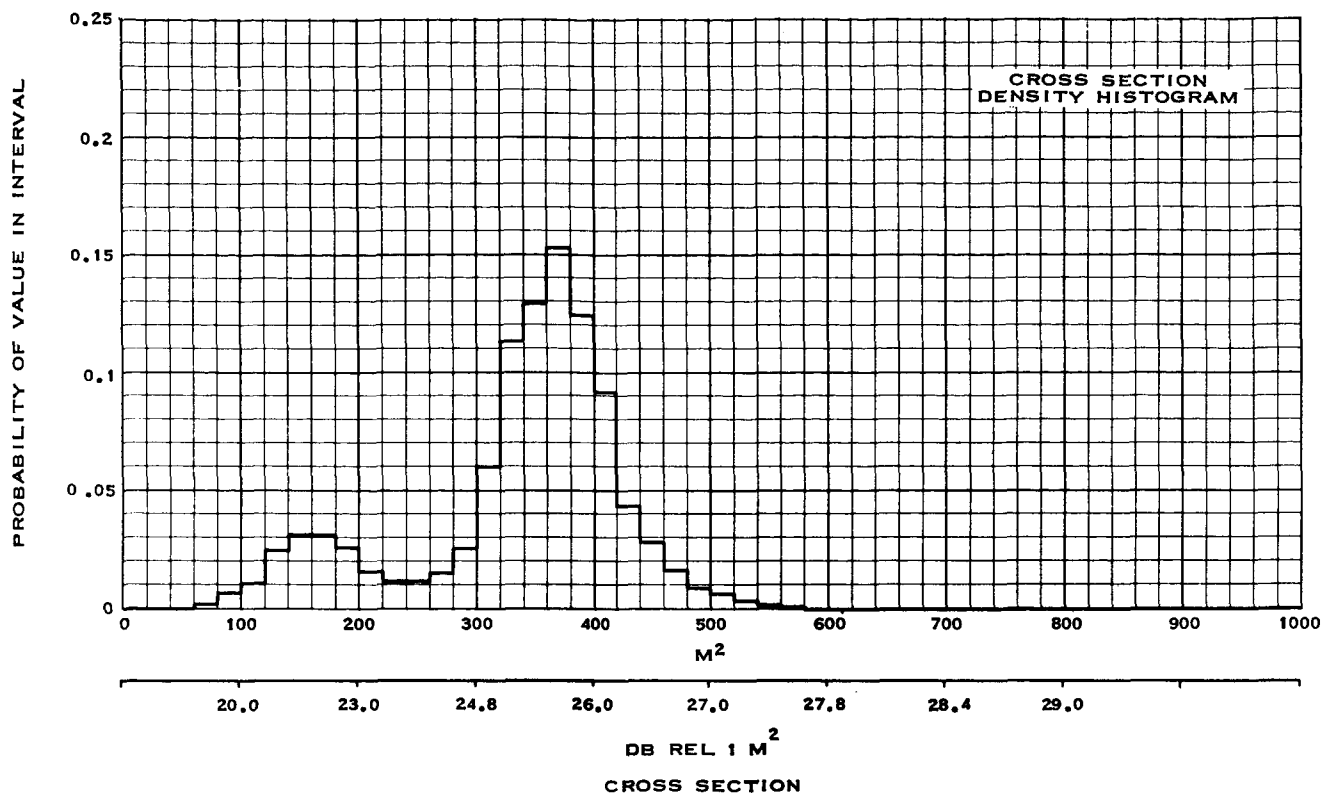


Figure 14. Pass No. 57 Data (Sheet 2 of 2)

PASS NO. 72

PASS DATE 18 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = 271.01 M²
24.33 DB REL ONE M²

MEDIAN CROSS SECTION = 269 M²
24.3 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 54.581 M²

LOWER DEVIATION FROM MEAN = 57.684 M²

SKEWNESS = 0.95

NO. OF DATA SAMPLES = 5185

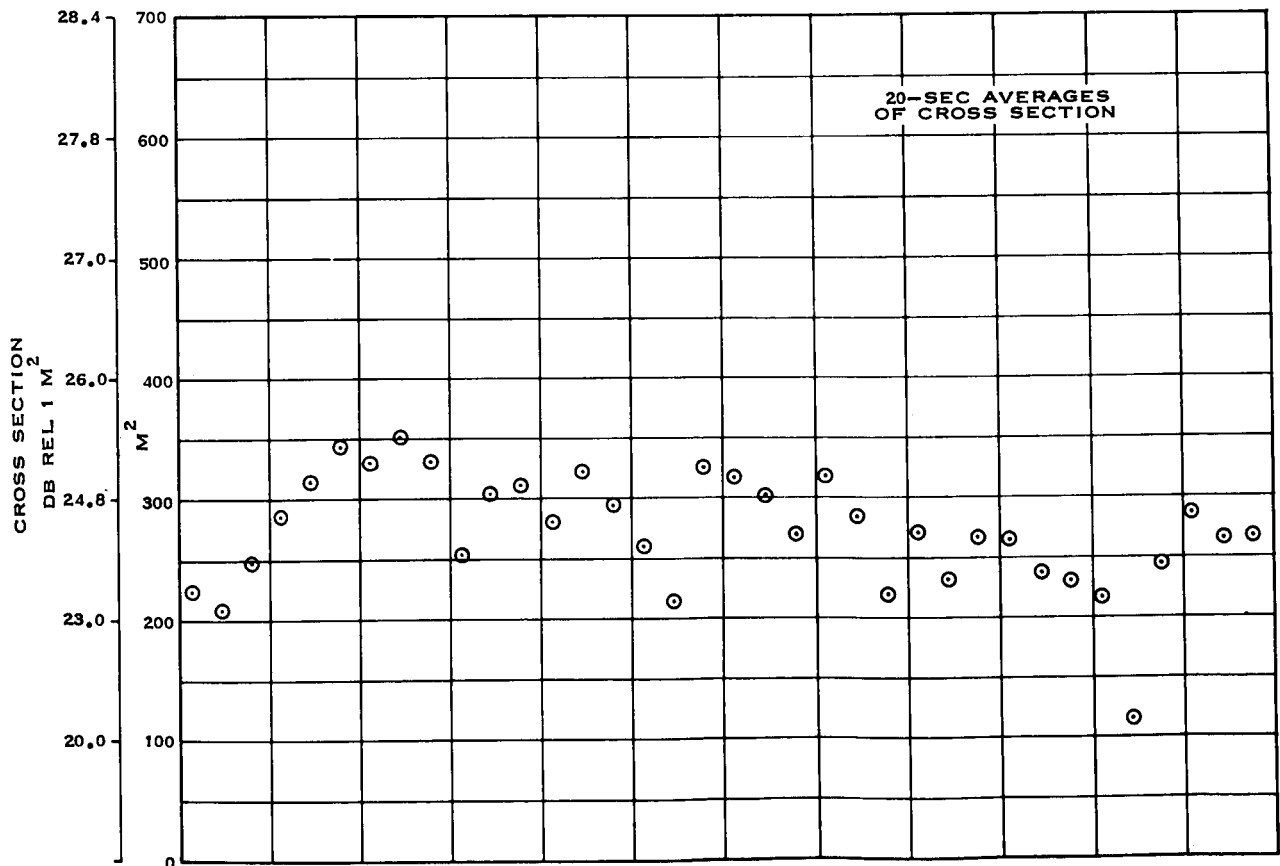
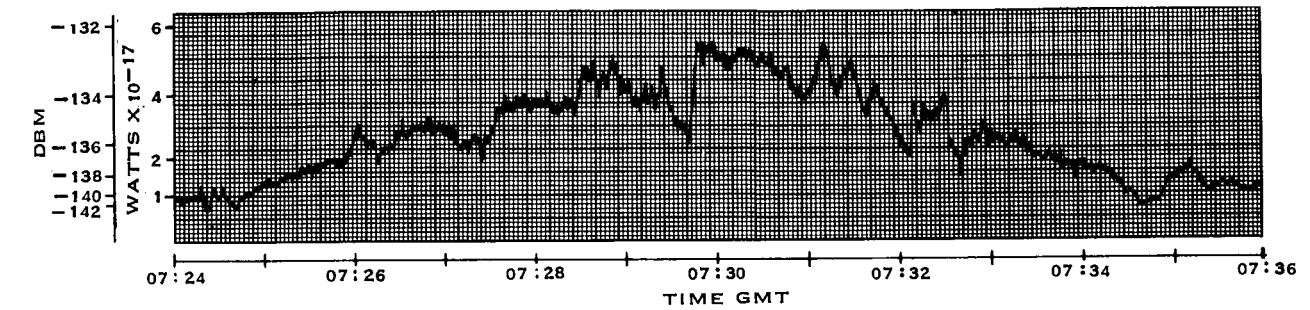


Figure 15. Pass No. 72 Data (Sheet 1 of 2)

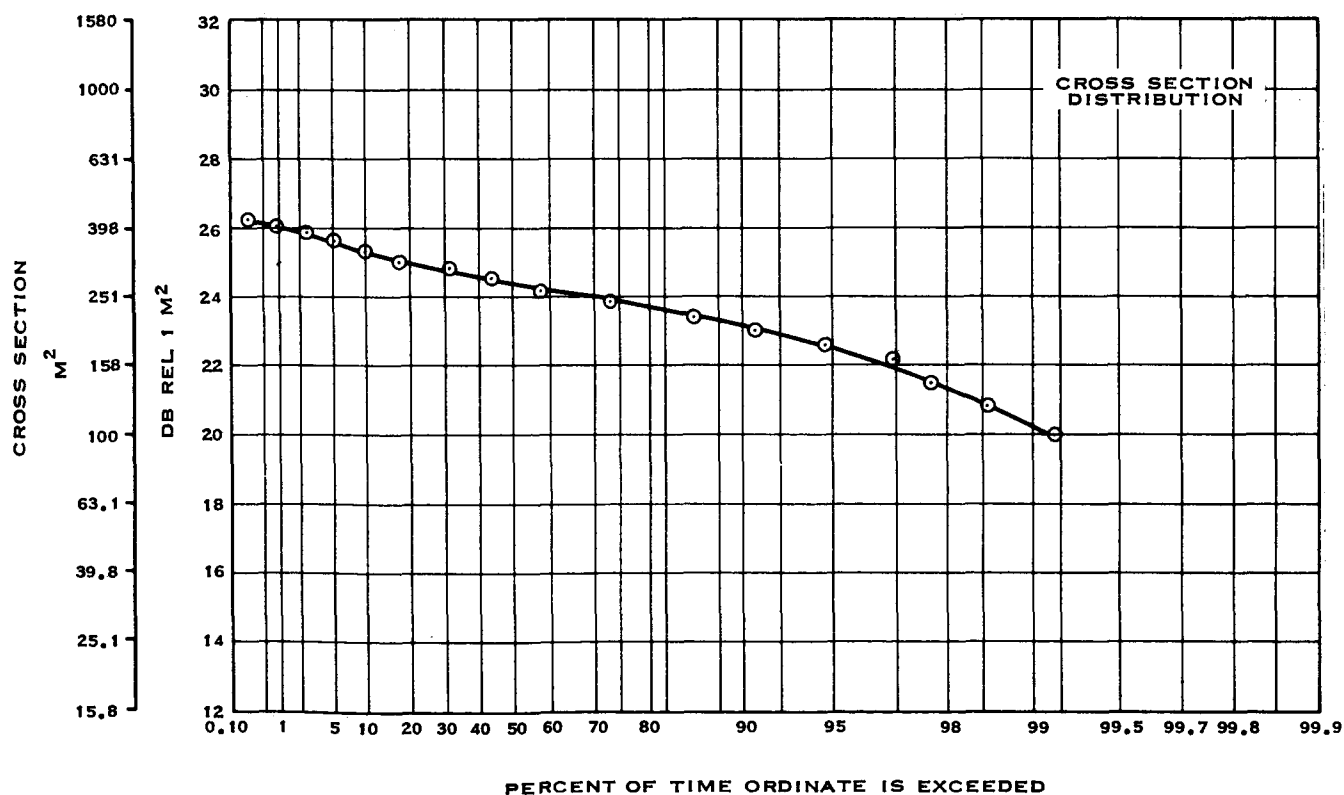
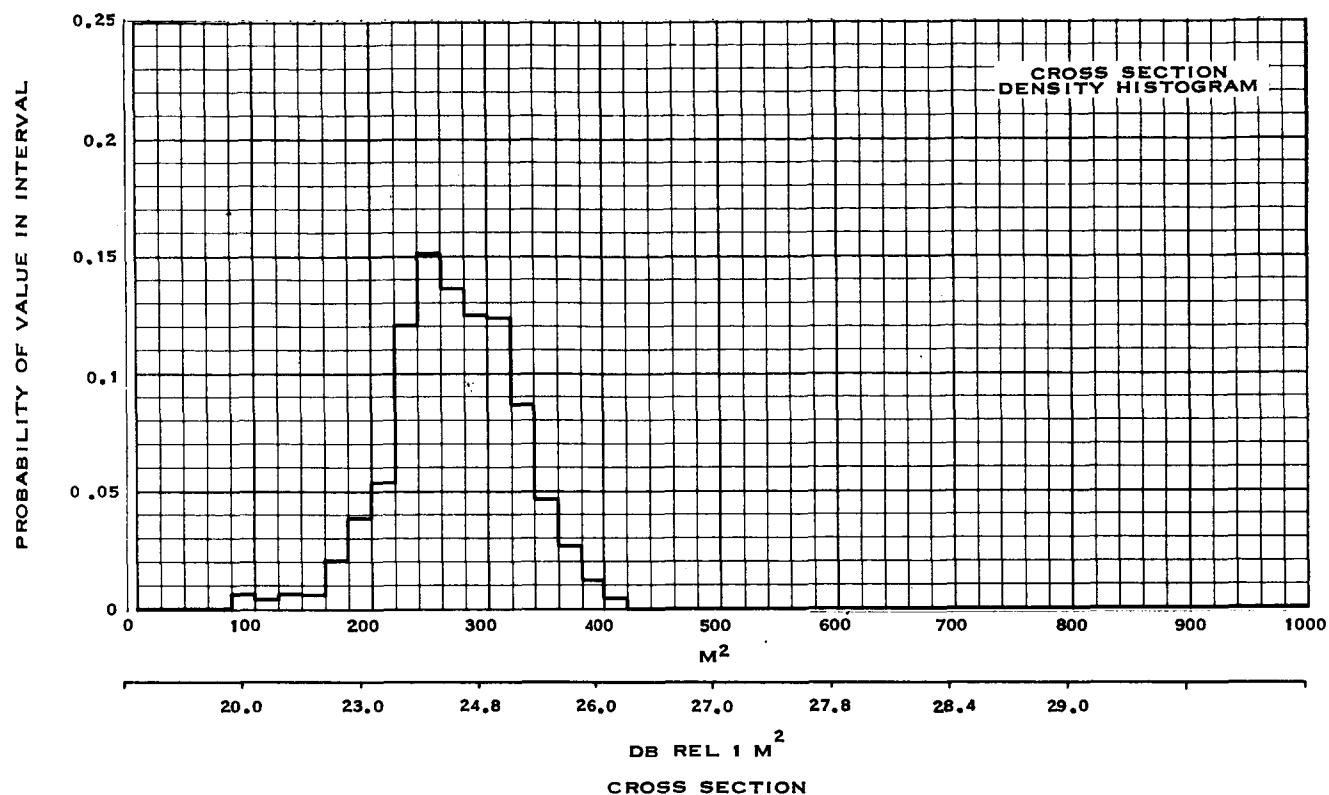


Figure 15. Pass No. 72 Data (Sheet 2 of 2)

PASS NO. 84

PASS DATE 19 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = $51,677 \text{ M}^2$
17.12 DB REL ONE M^2

MEDIAN CROSS SECTION = $50,1 \text{ M}^2$
17.0 DB REL ONE M^2

UPPER DEVIATION FROM MEAN = $16,449 \text{ M}^2$

LOWER DEVIATION FROM MEAN = $12,460 \text{ M}^2$

SKEWNESS = 1.32

NO. OF DATA SAMPLES = 3612

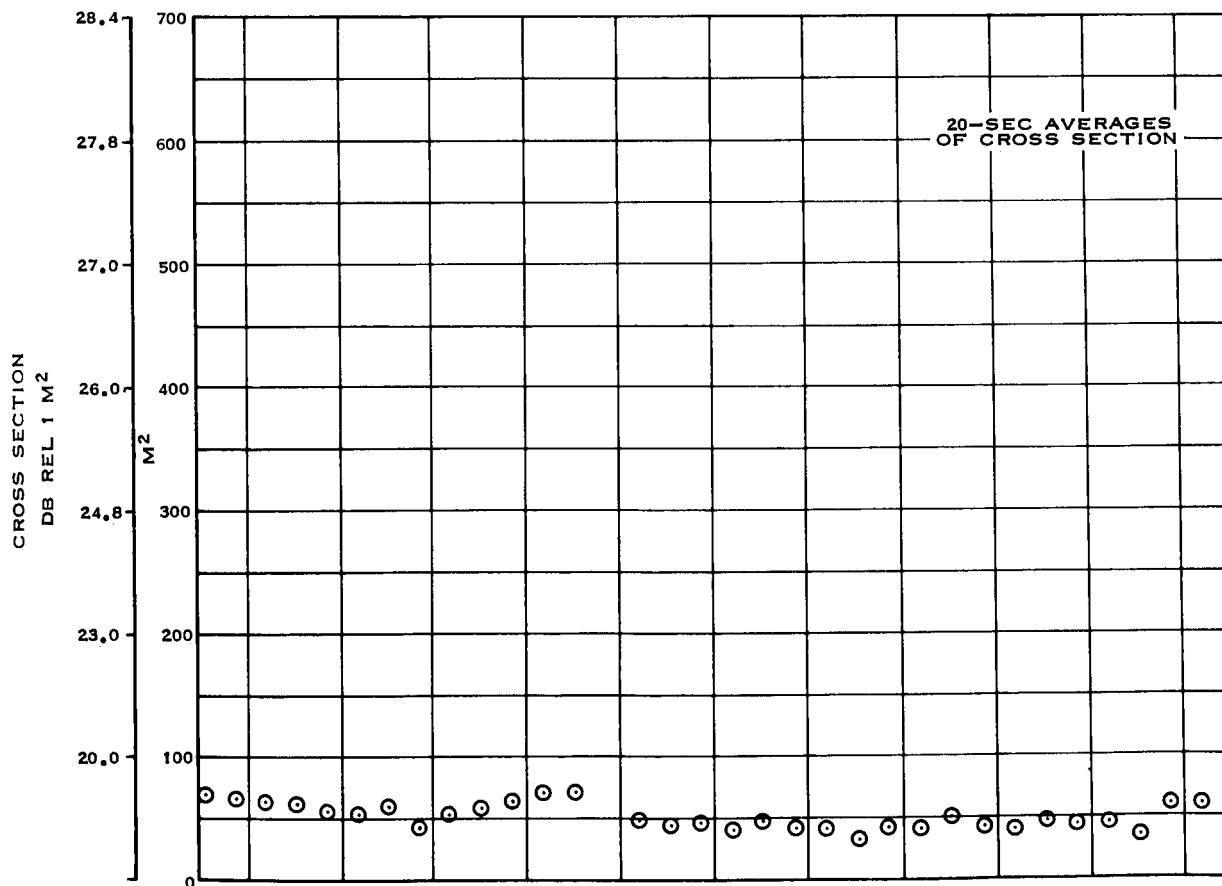
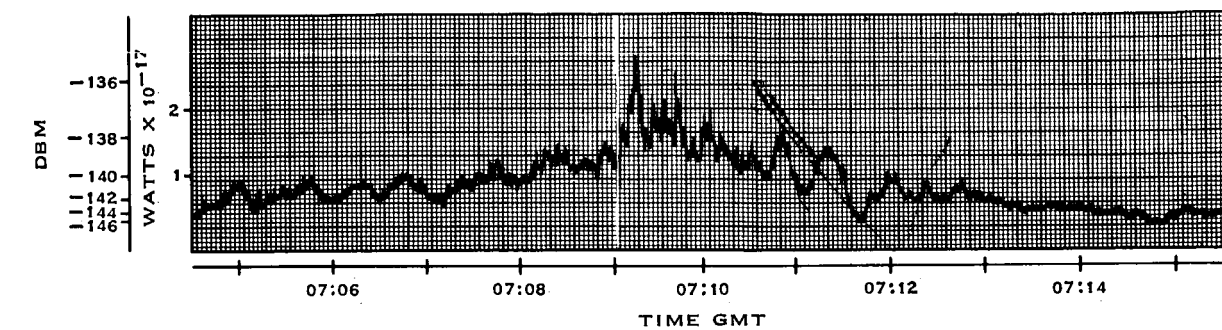


Figure 16. Pass No. 84 Data (Sheet 1 of 2)

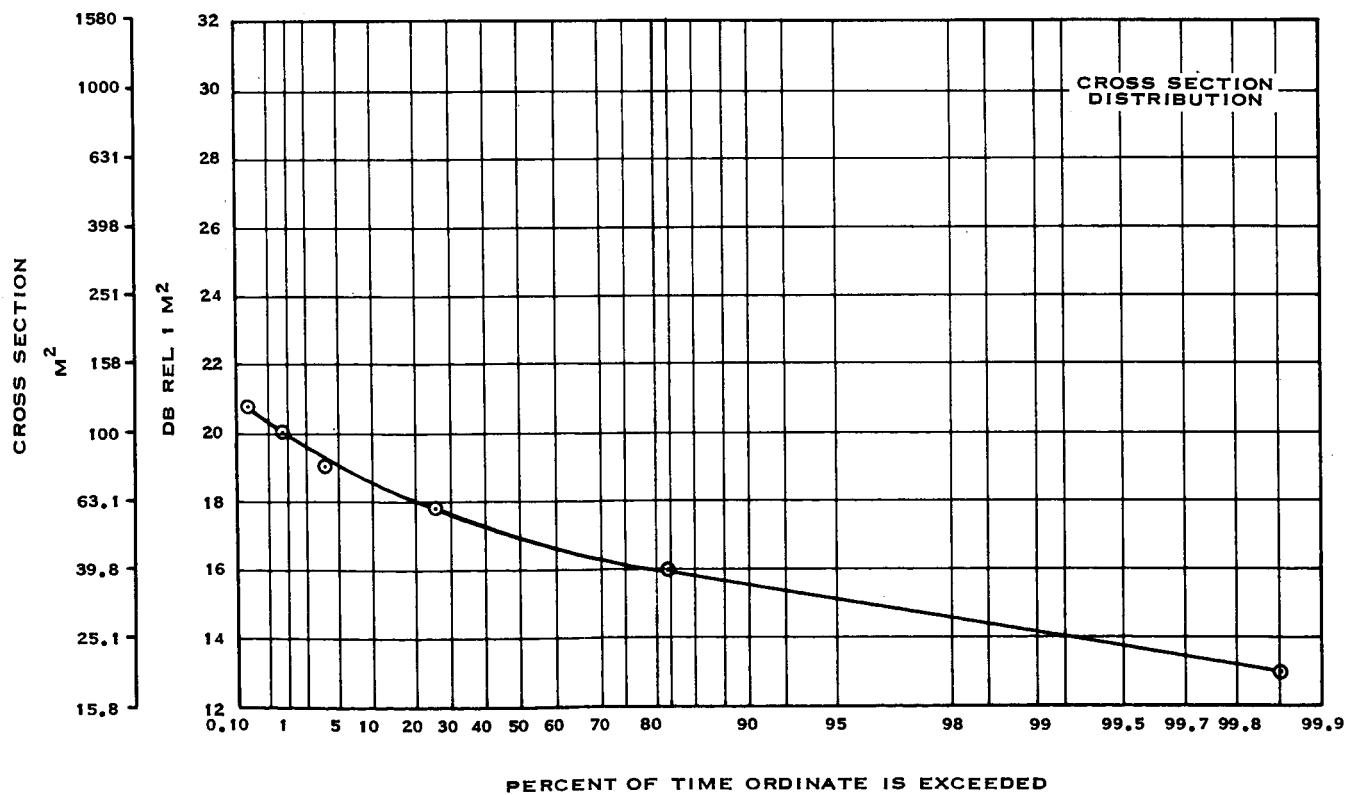
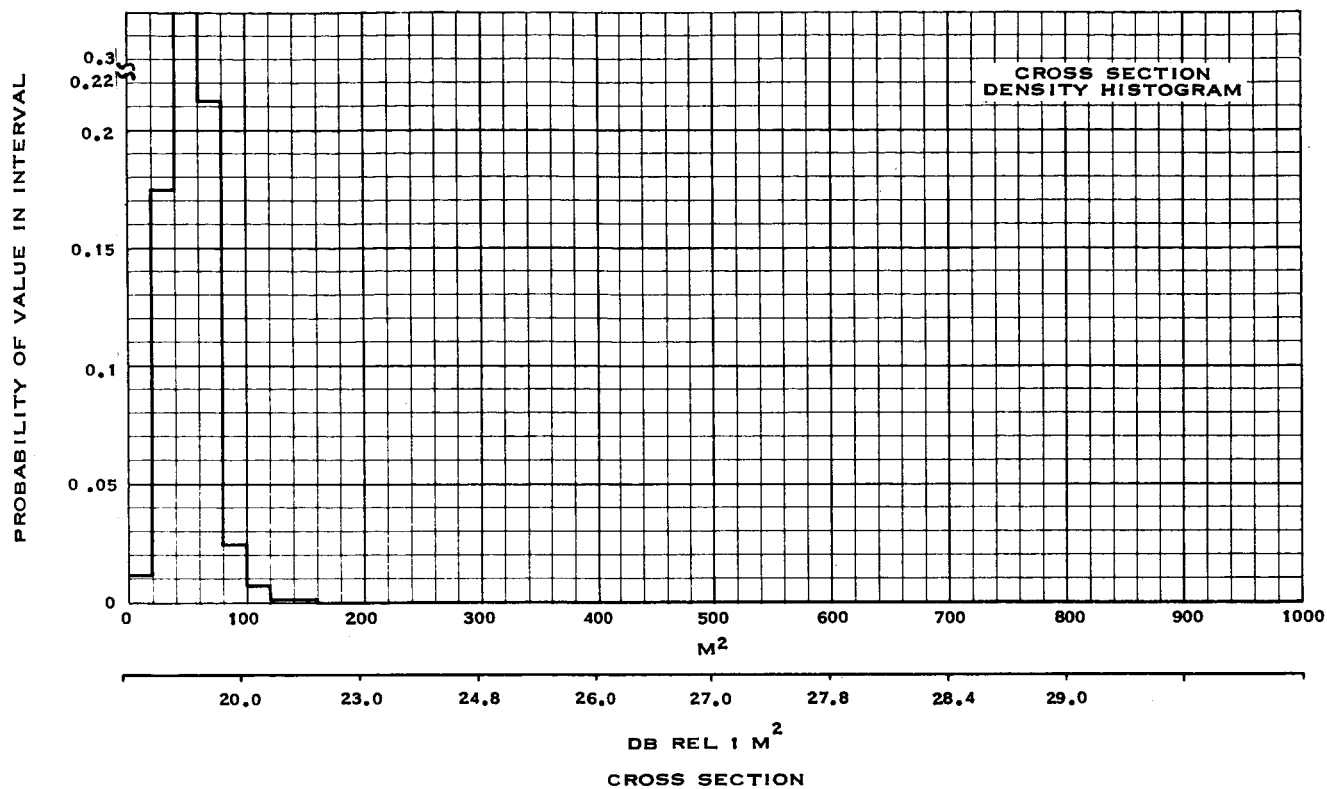


Figure 16. Pass No. 84 Data (Sheet 2 of 2)

PASS NO. 95

PASS DATE 20 AUGUST 1960 = BISTATIC DATA

MEAN CROSS SECTION = 400.64 M^2
26.04 DB REL ONE M^2

MEDIAN CROSS SECTION = 390 M^2
25.9 DB REL ONE M^2

UPPER DEVIATION FROM MEAN = 149.74 M^2

LOWER DEVIATION FROM MEAN = 129.04 M^2

SKEWNESS = 1.16

NO. OF DATA SAMPLES = 3466

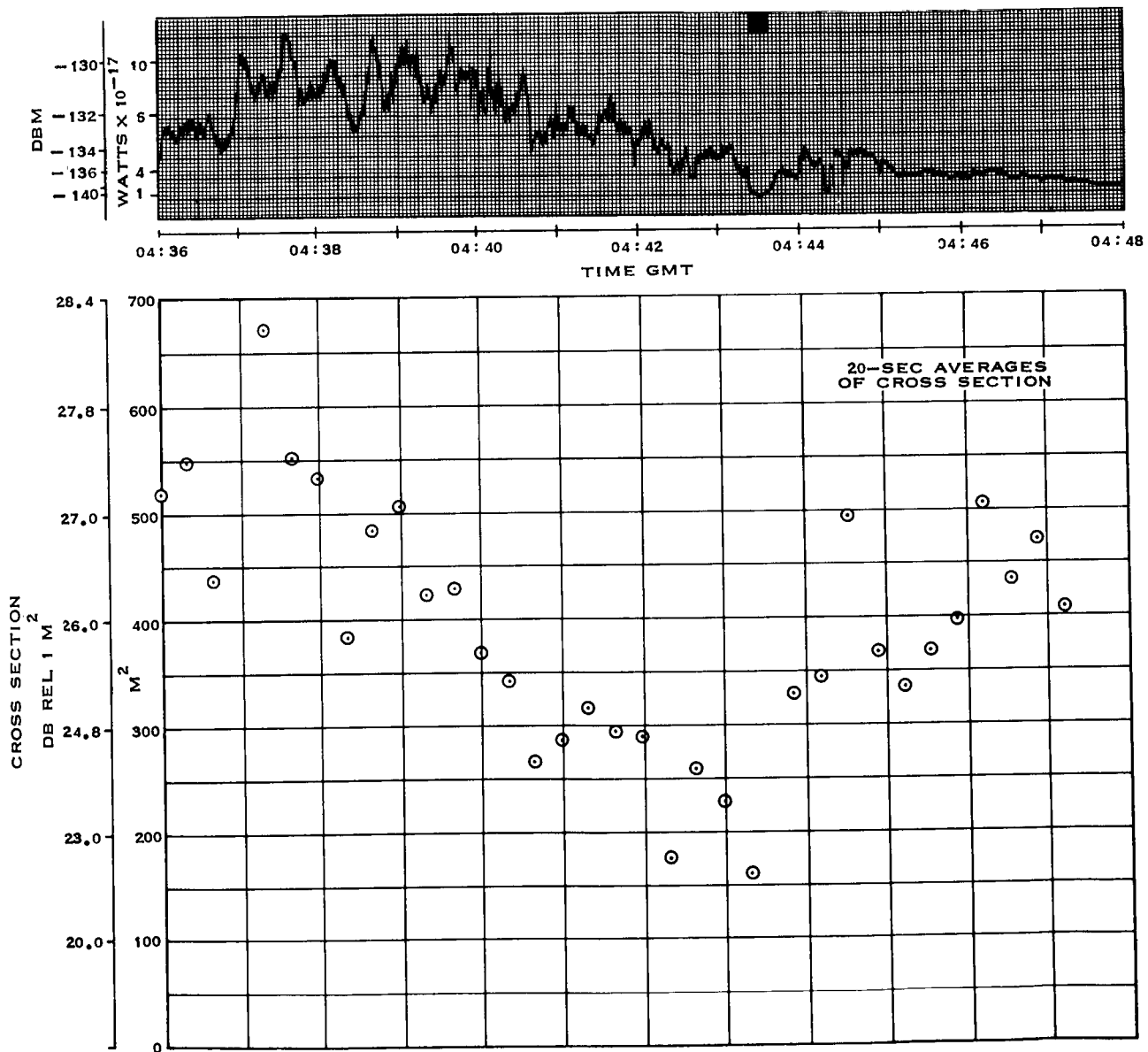


Figure 17. Pass No. 95 Data (Sheet 1 of 2)

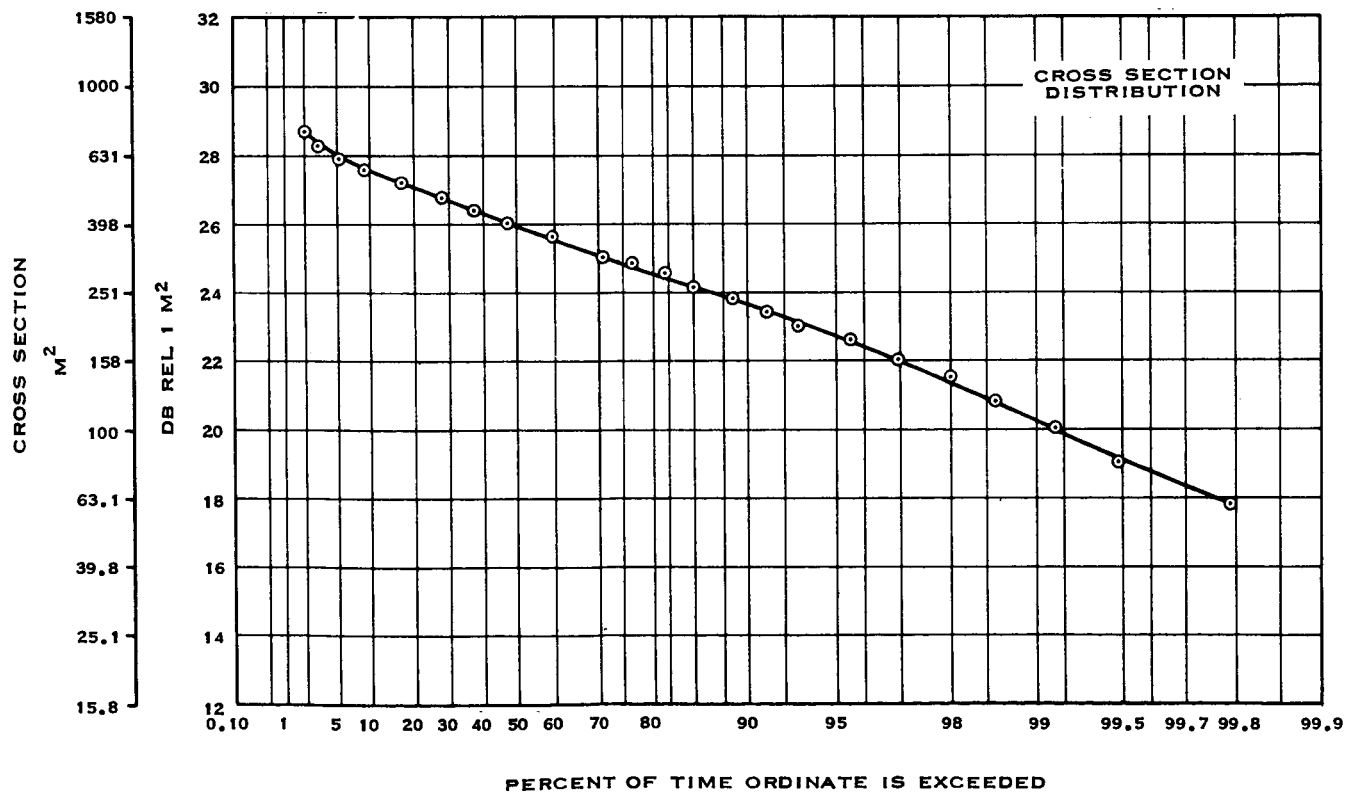
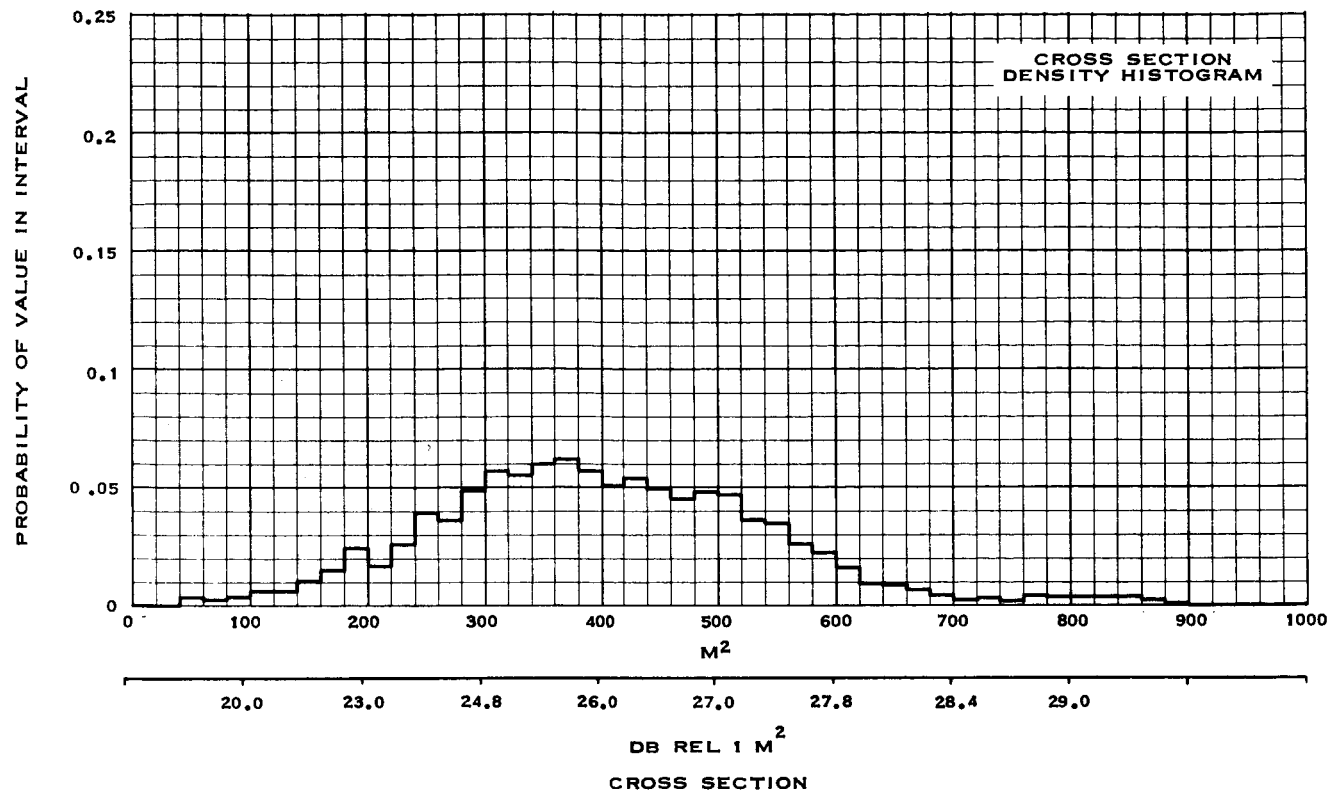


Figure 17. Pass No. 95 Data (Sheet 2 of 2)

PASS NO. 96

PASS DATE 20 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = 551.49 M²
27.41 DB REL ONE M²

MEDIAN CROSS SECTION = 575 M²
27.6 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 101.63 M²

LOWER DEVIATION FROM MEAN = 184.25 M²

SKEWNESS = 0.55

NO. OF DATA SAMPLES = 4792

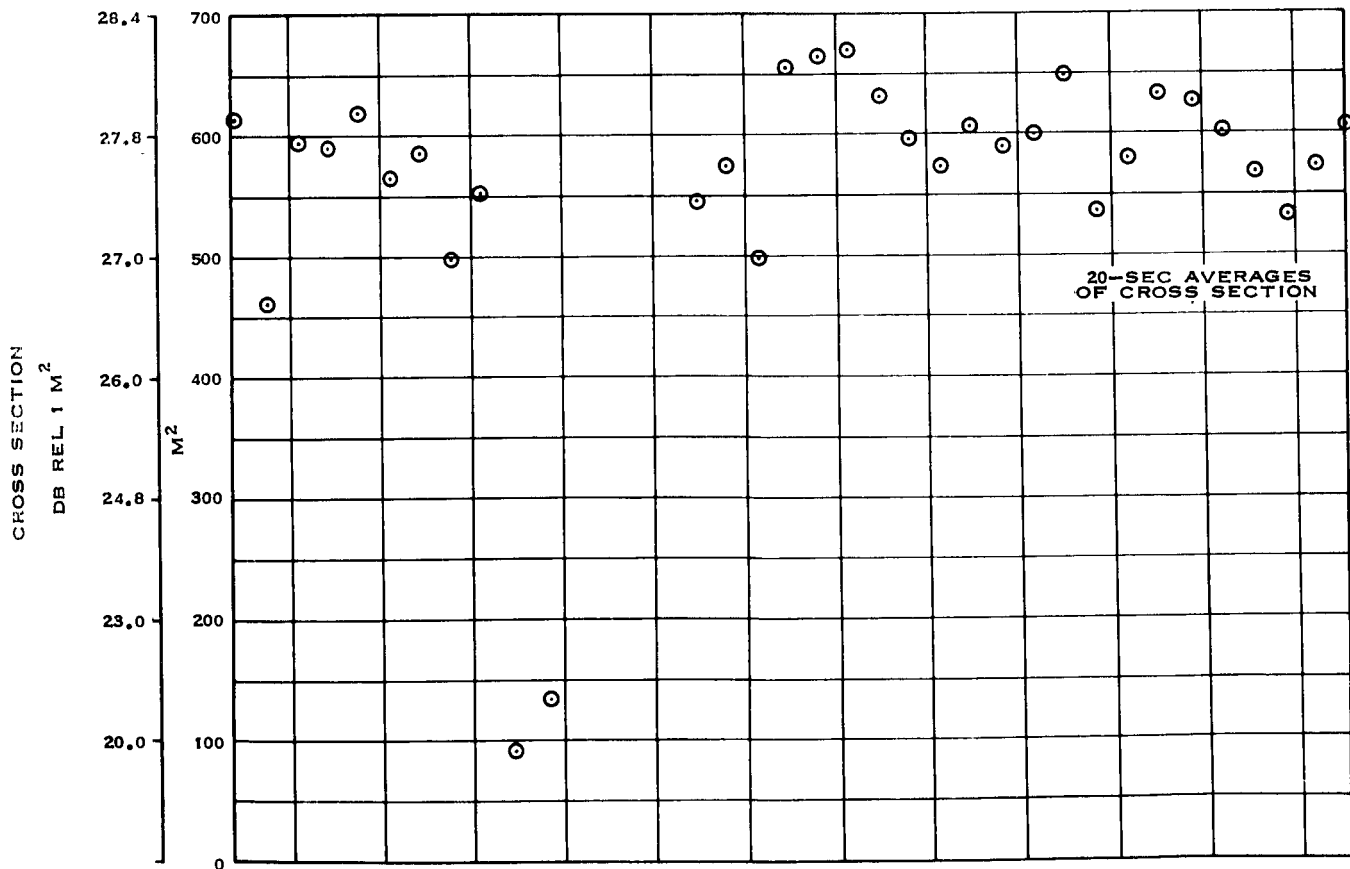
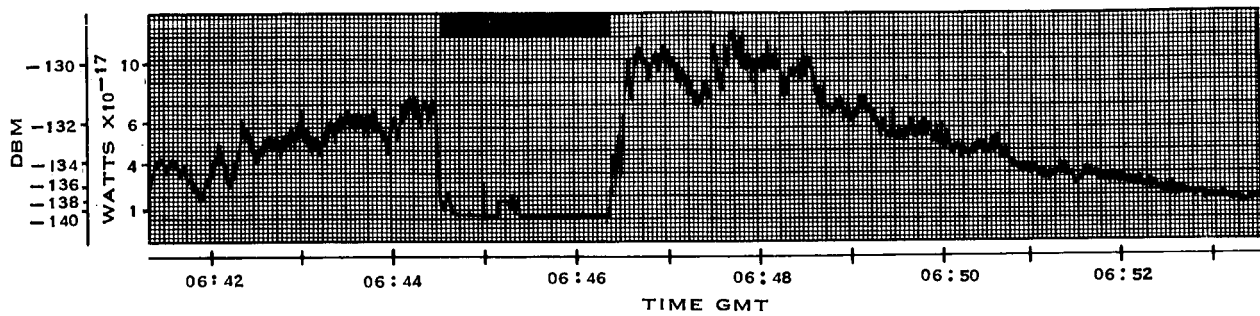


Figure 18. Pass No. 96 Data (Sheet 1 of 2)

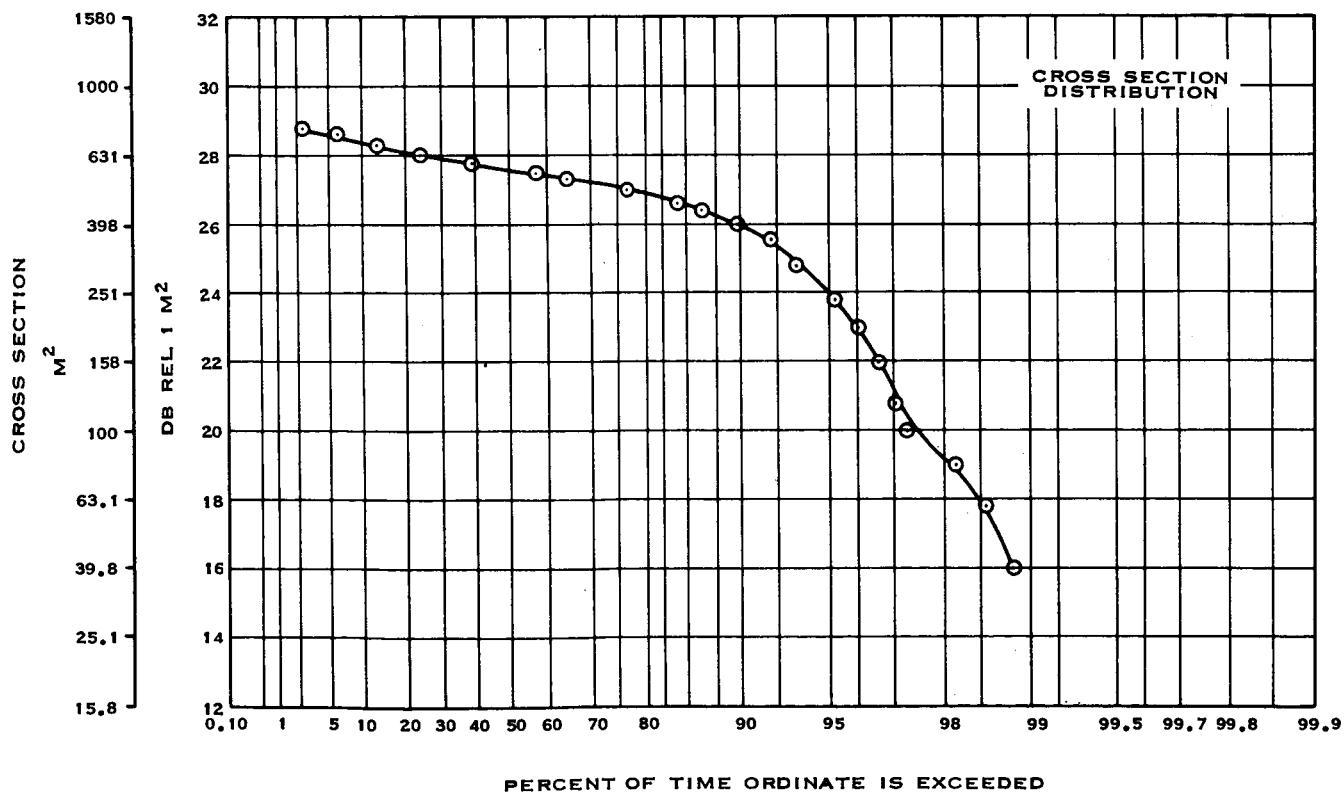
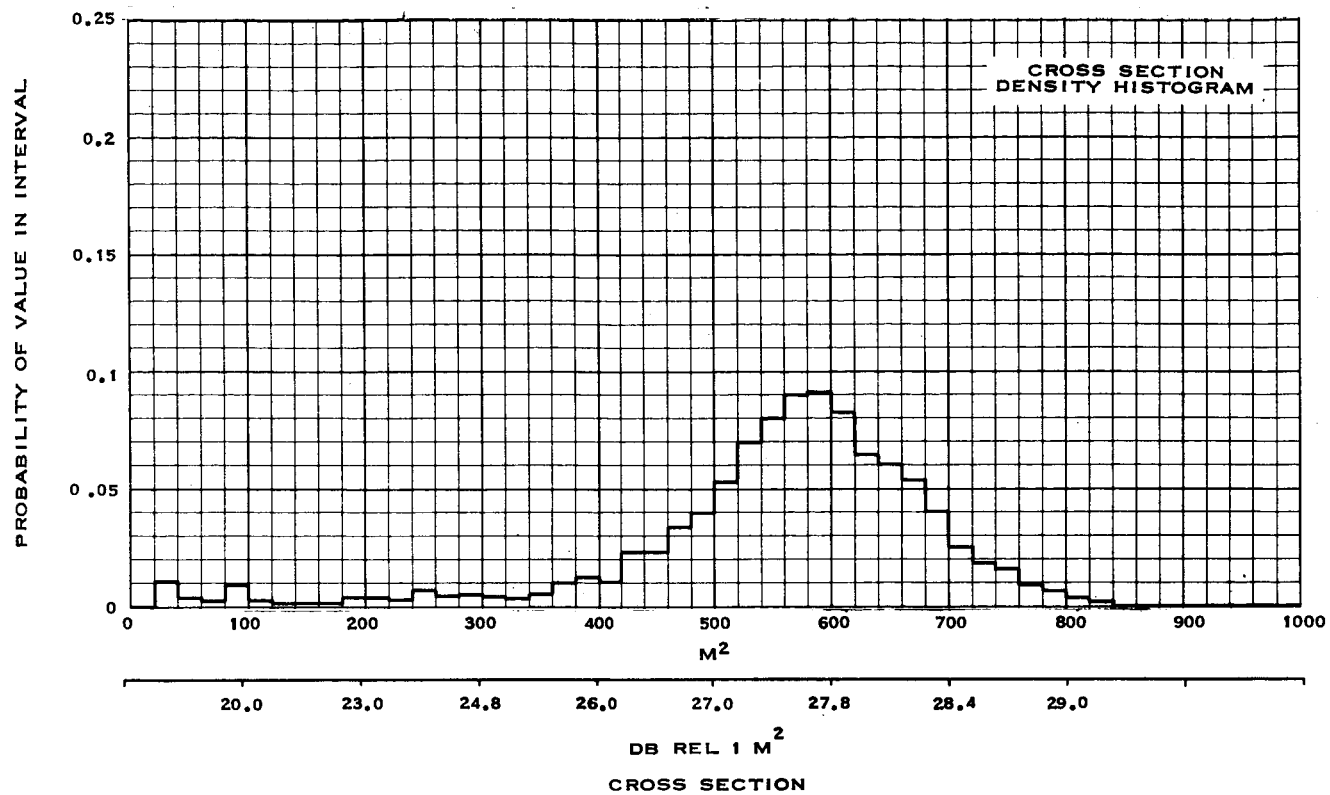


Figure 18. Pass No. 96 Data (Sheet 2 of 2)

PASS NO. 109

PASS DATE 21 AUGUST 1960

MONOSTATIC DATA

MEAN CROSS SECTION = 381.87 M²
25.82 DB REL ONE M²

MEDIAN CROSS SECTION = 295 M²
24.7 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 292.38 M²

LOWER DEVIATION FROM MEAN = 171.66 M²

SKEWNESS = 1.70

NO. OF DATA SAMPLES = 3741

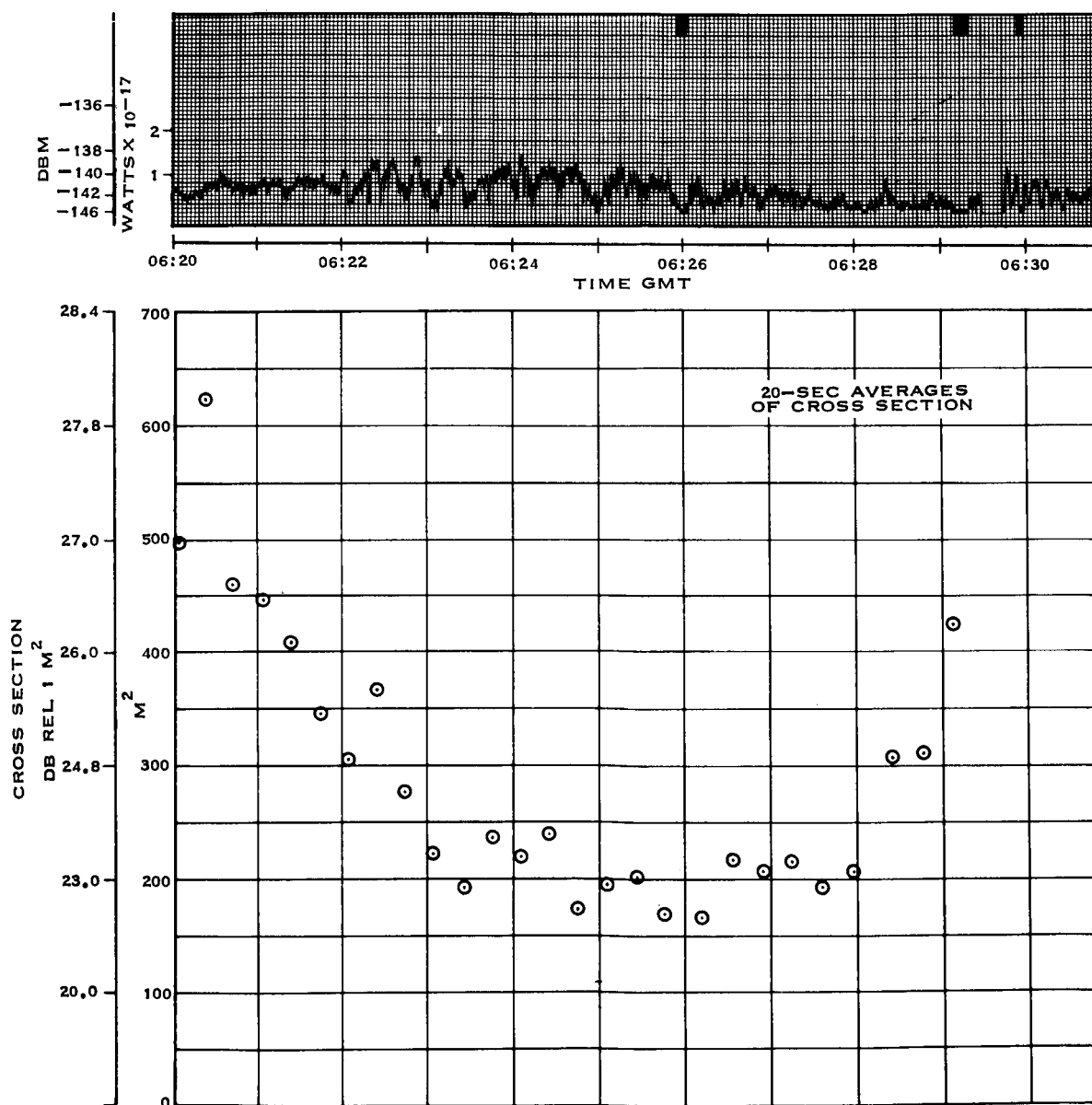


Figure 19. Pass No. 109 Data (Sheet 1 of 2)

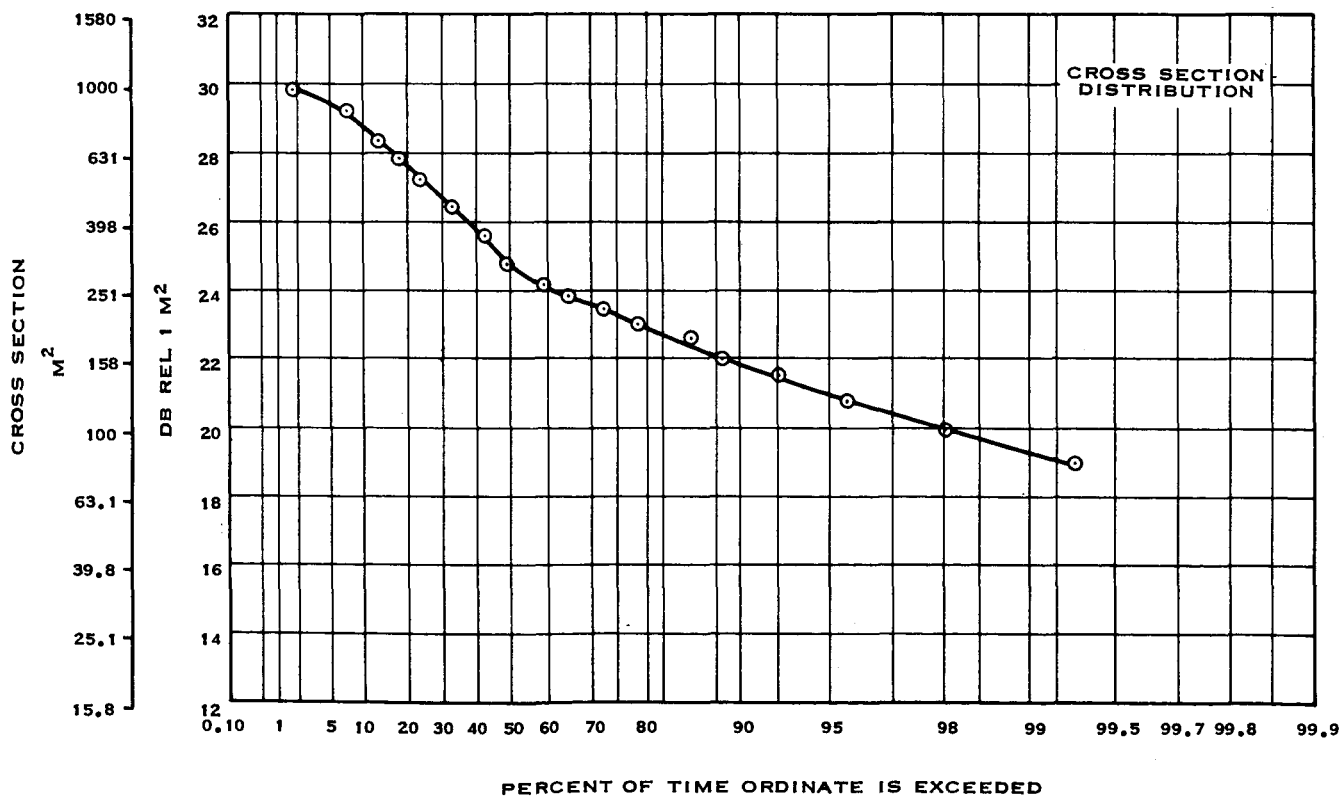
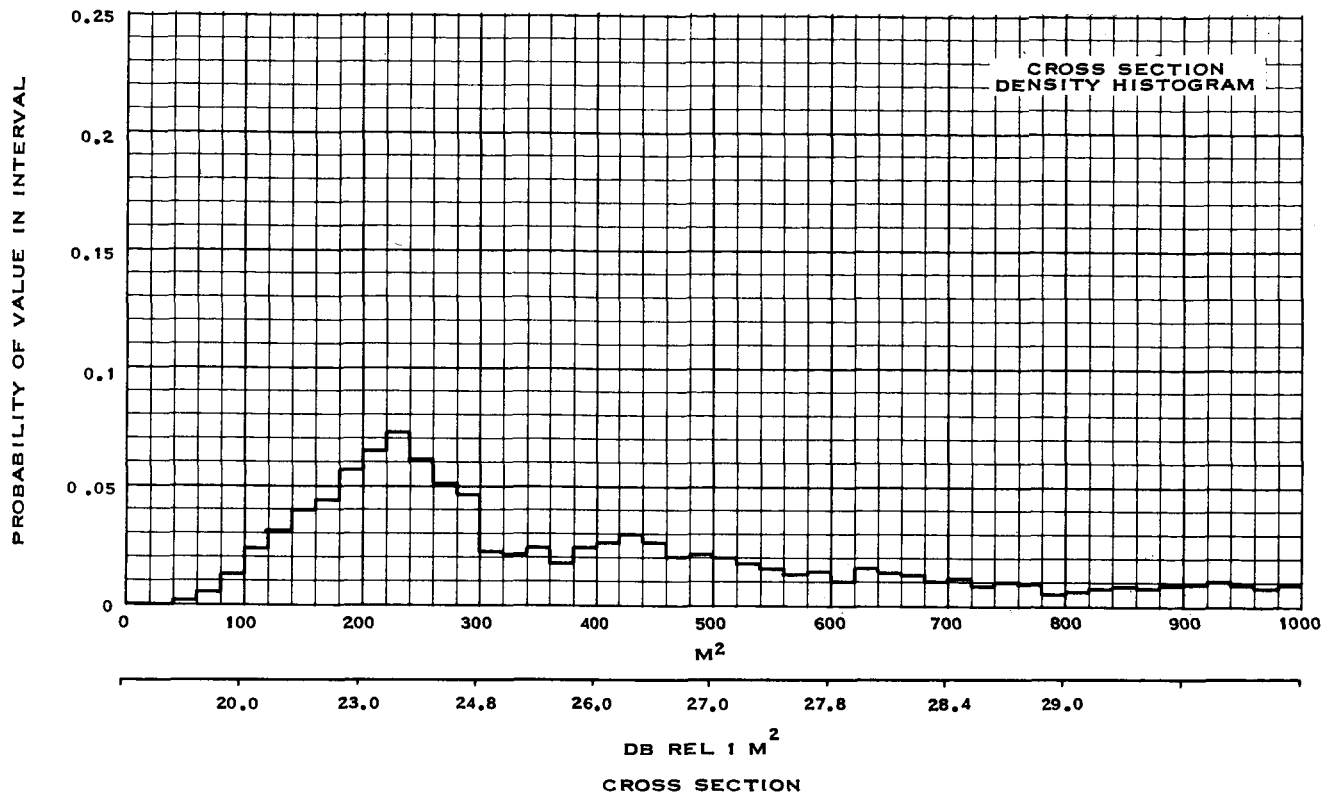


Figure 19. Pass No. 109 Data (Sheet 2 of 2)

PASS NO. 120

PASS DATE 22 AUGUST 1960

MONOSTATIC DATA

MEAN CROSS SECTION = 460.60 M²
26.64 DB REL ONE M²

MEDIAN CROSS SECTION = 437 M²
26.4 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 182.33 M²

LOWER DEVIATION FROM MEAN = 141.12 M²

SKEWNESS = 1.30

NO. OF DATA SAMPLES = 3840

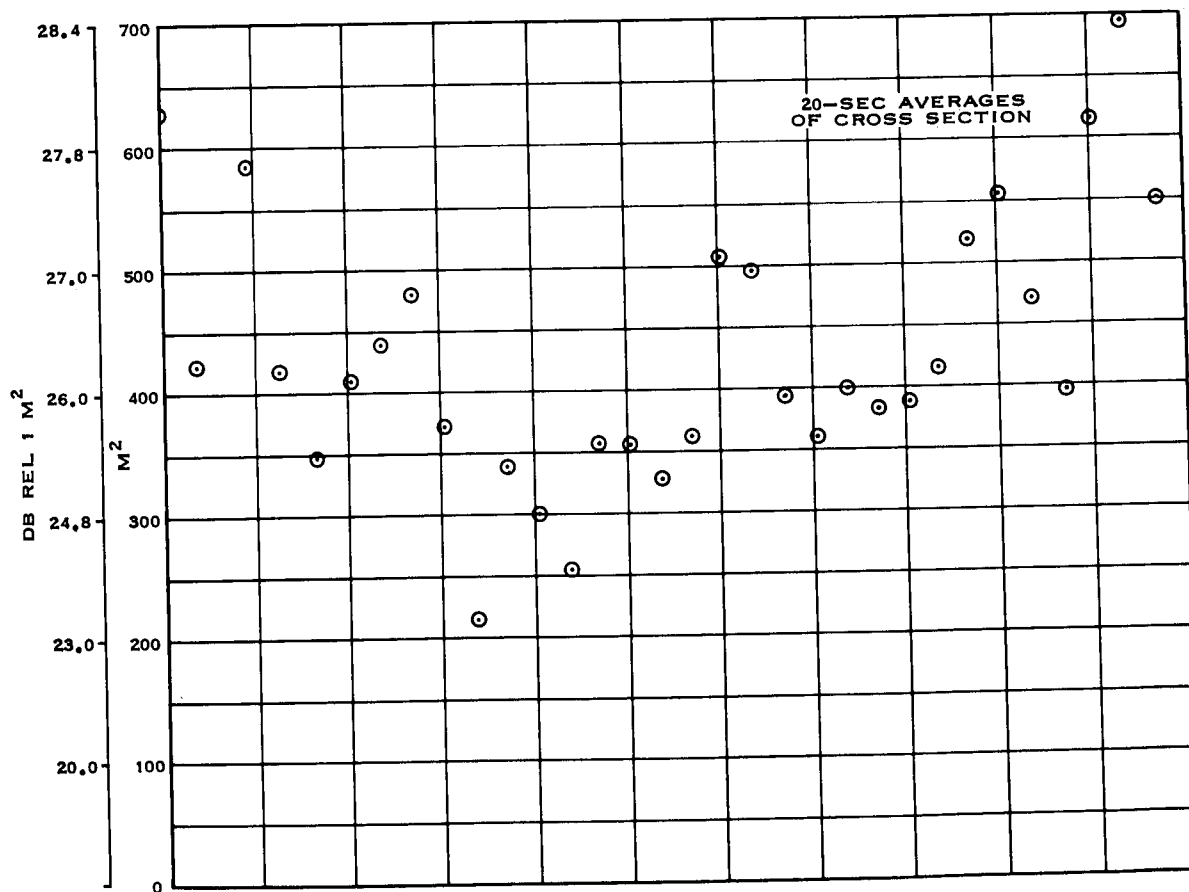
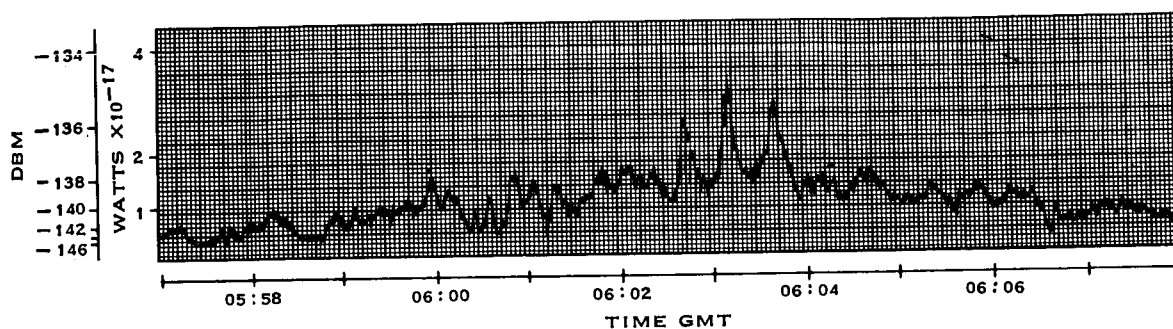


Figure 20. Pass No. 120 Data (Sheet 1 of 2)

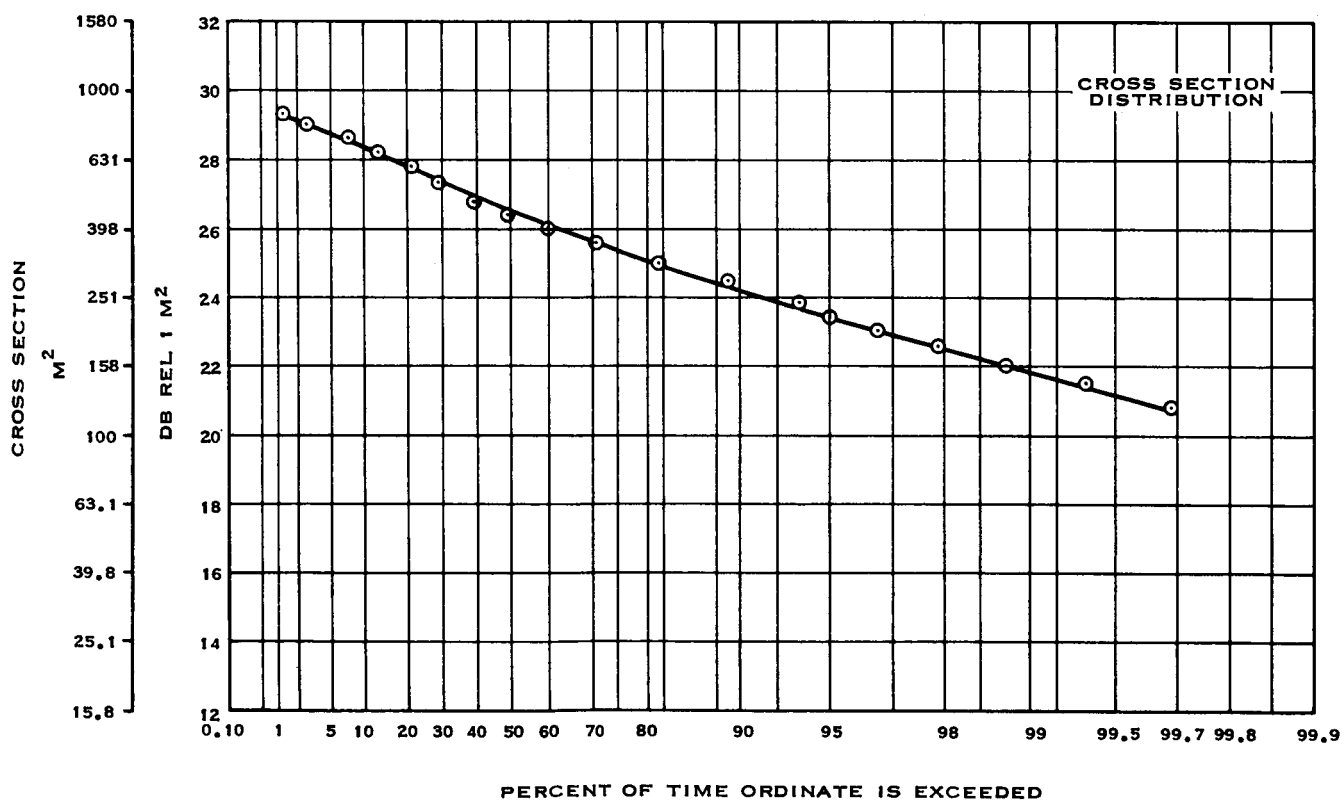
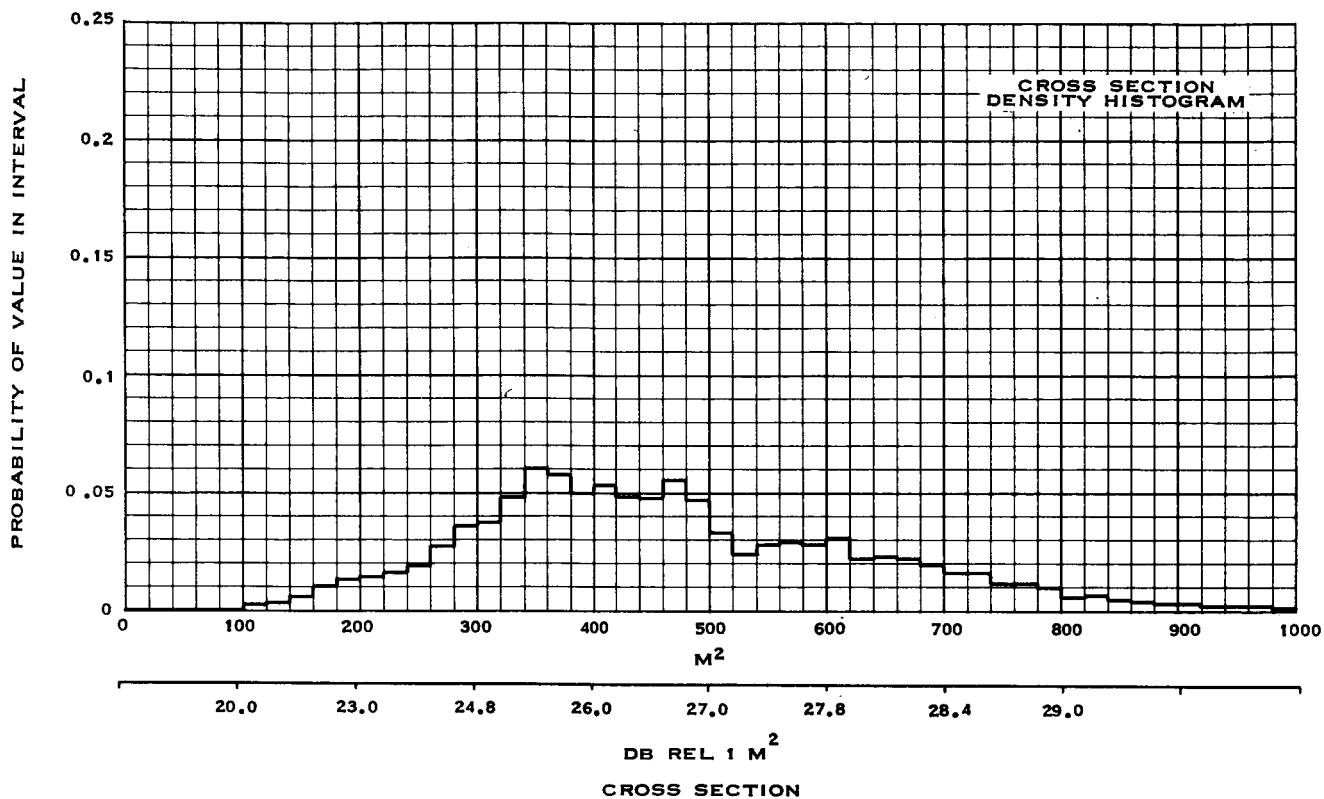


Figure 20. Pass No. 120 Data (Sheet 2 of 2)

PASS NO. 131

PASS DATE 23 AUGUST 1960

MONOSTATIC DATA

MEAN CROSS SECTION = 415.28 M²
26.18 DB REL ONE M²

MEDIAN CROSS SECTION = 331 M²
25.2 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 286.98 M²

LOWER DEVIATION FROM MEAN = 159.71 M²

SKEWNESS = 1.80

NO. OF DATA SAMPLES = 3867

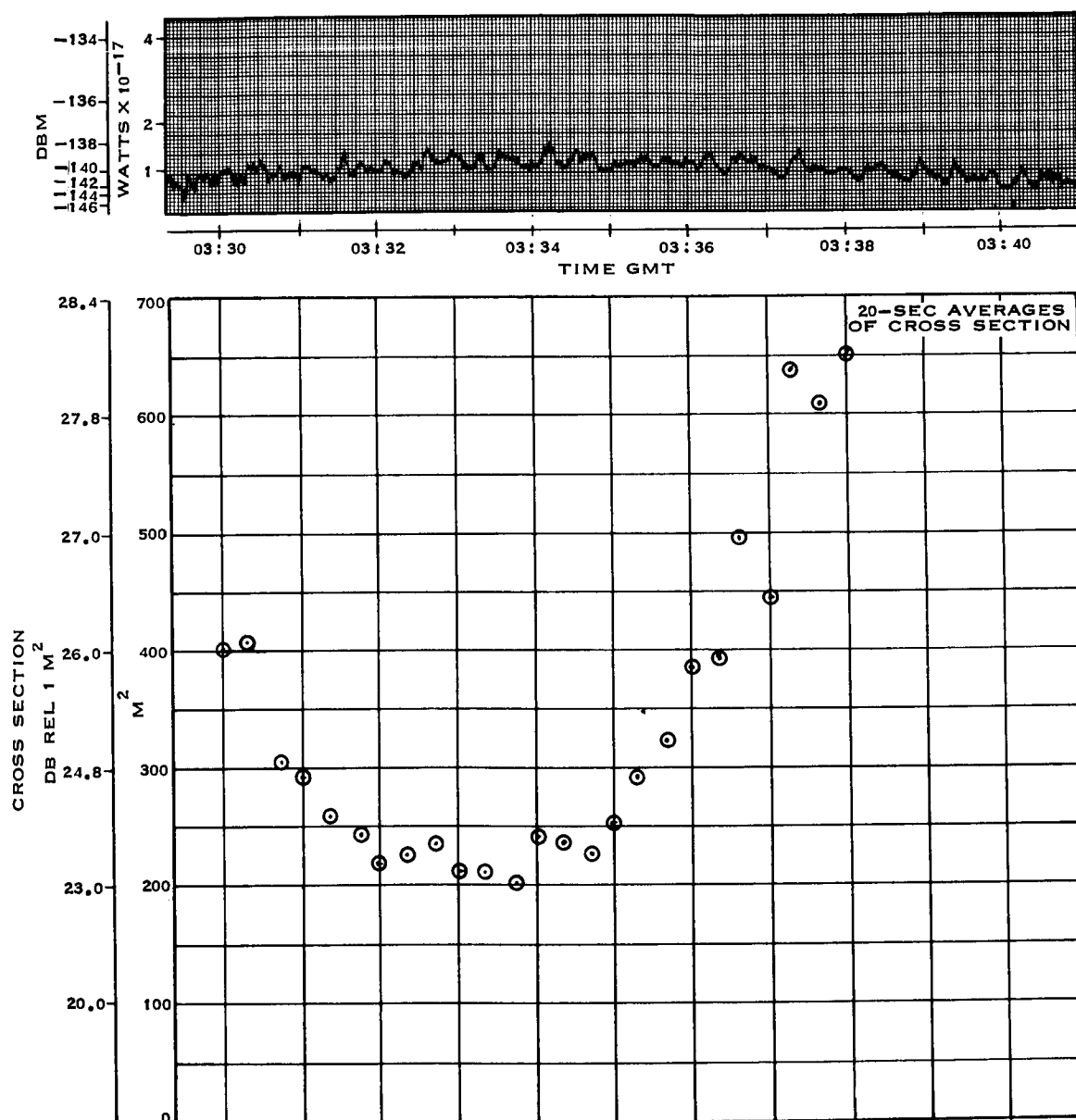


Figure 21. Pass No. 131 Data (Sheet 1 of 2)

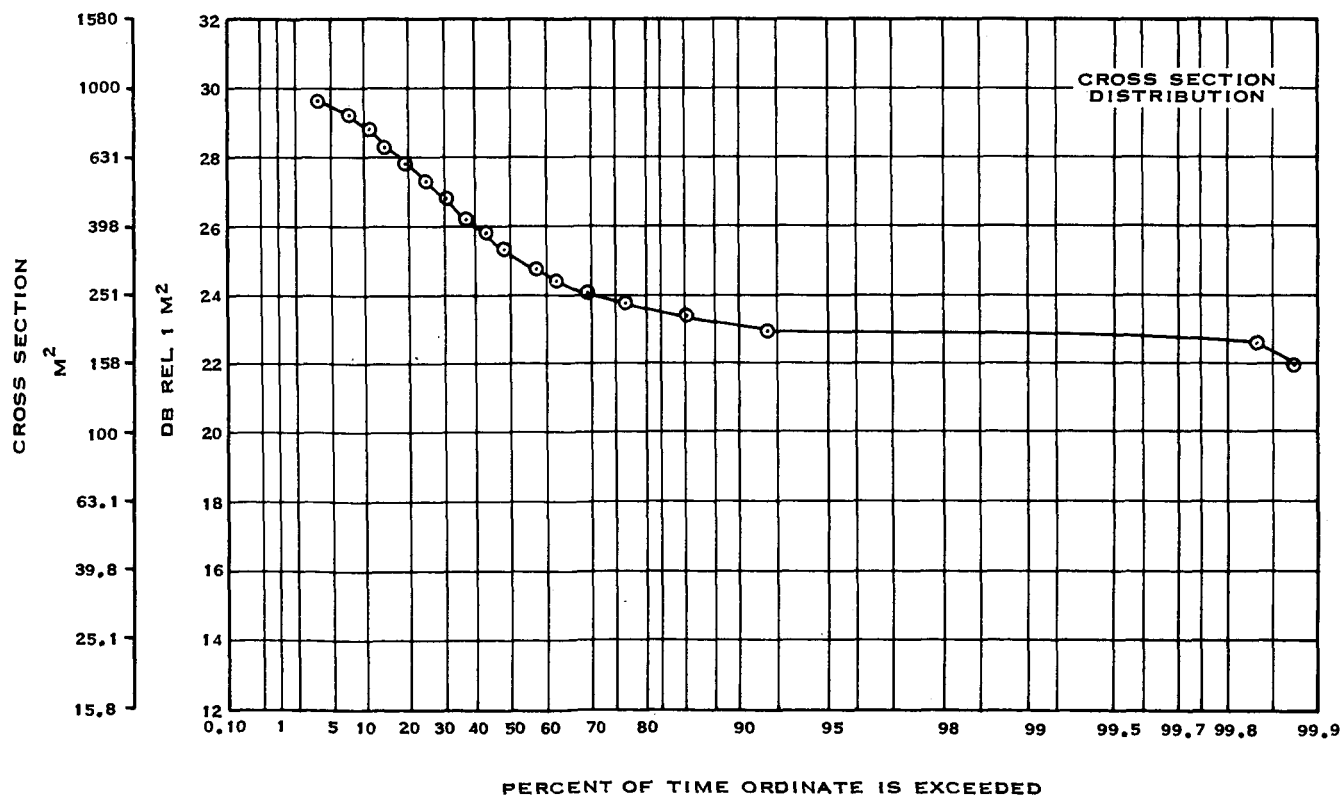
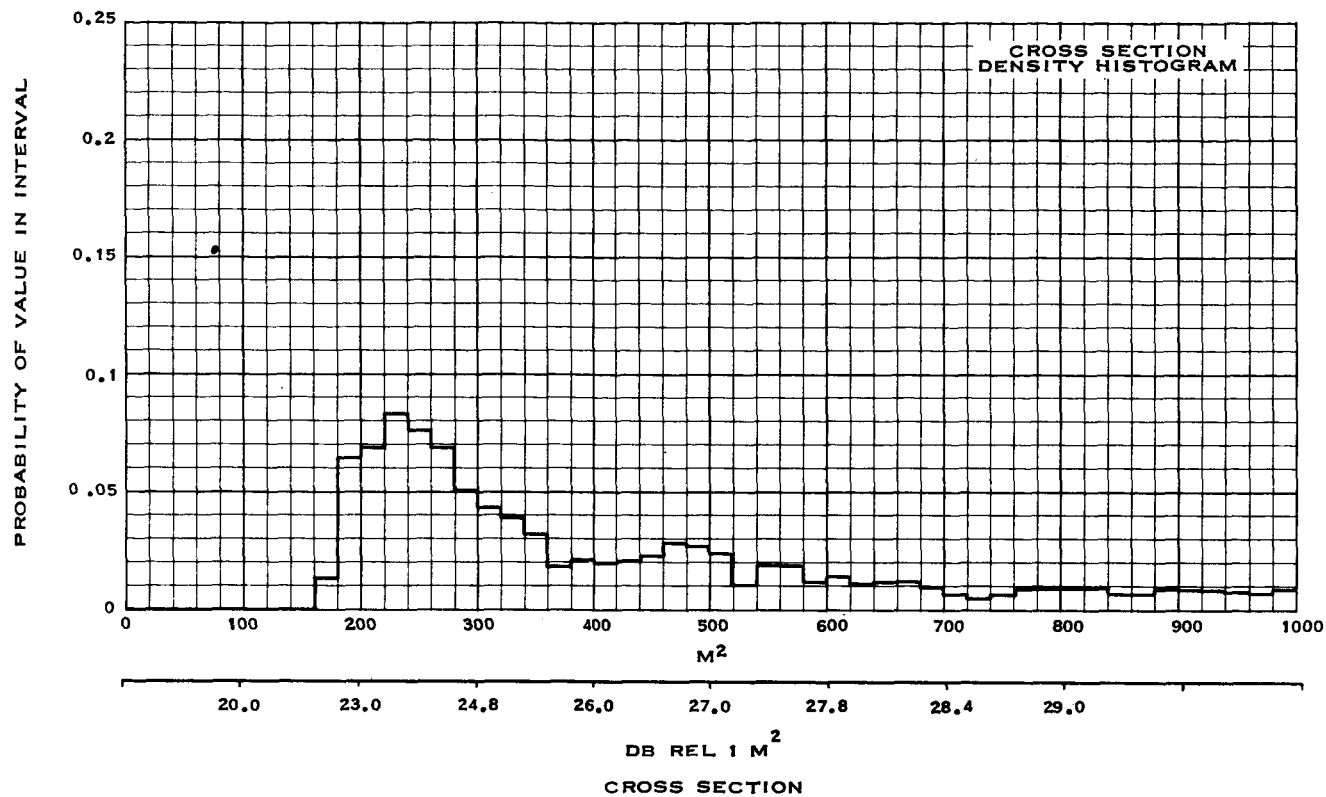


Figure 21. Pass No. 131 Data (Sheet 2 of 2)

PASS NO. 132

PASS DATE 23 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = 351.35 M^2
25.45 DB REL ONE M^2

MEDIAN CROSS SECTION = 339 M^2
25.3 DB REL ONE M^2

UPPER DEVIATION FROM MEAN = 139.70 M^2

LOWER DEVIATION FROM MEAN = 116.11 M^2

SKEWNESS = 1.20

NO. OF DATA SAMPLES = 2009

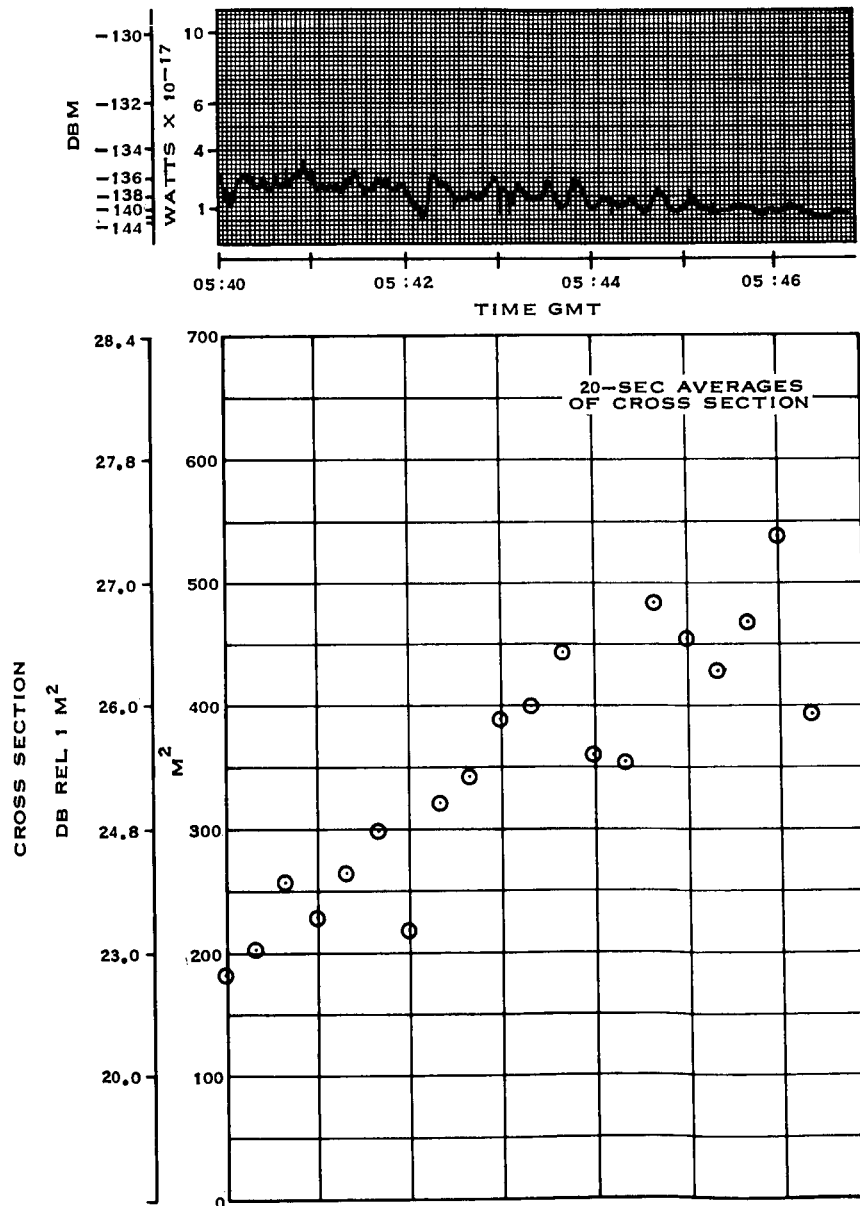


Figure 22. Pass No. 132 Data (Sheet 1 of 2)

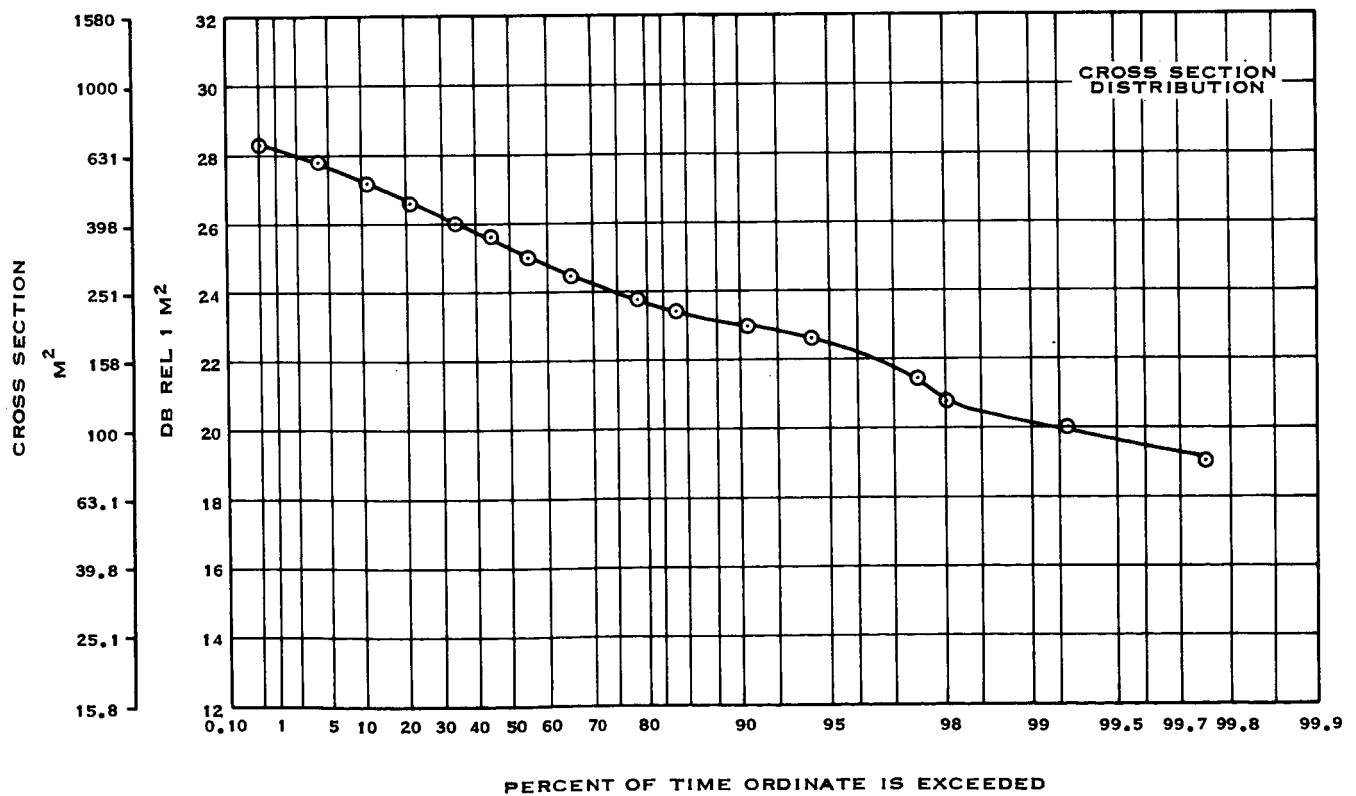
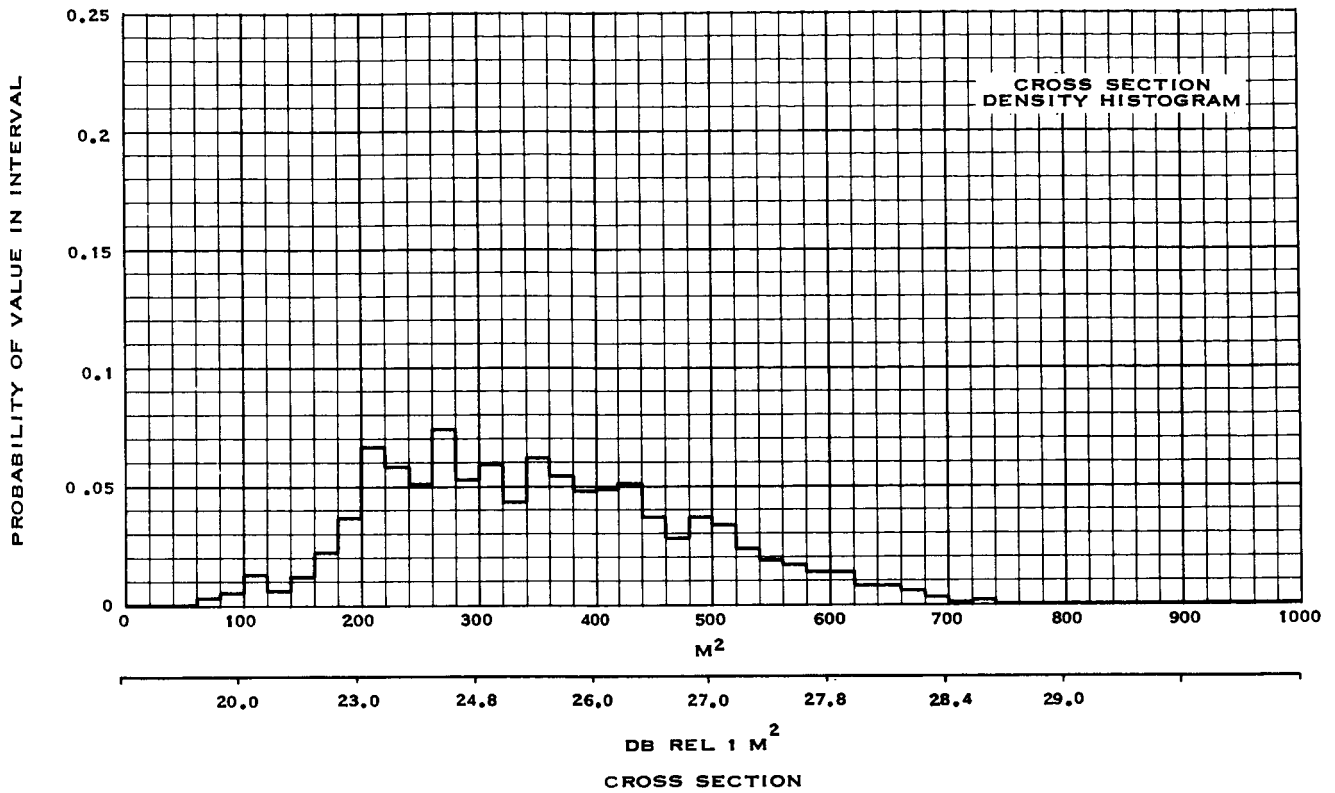


Figure 22. Pass No. 132 Data (Sheet 2 of 2)

PASS NO. 143

PASS DATE 24 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = 247.89 M^2
23.9 DB REL ONE M^2

MEDIAN CROSS SECTION = $246. \text{M}^2$
23.9 DB REL ONE M^2

UPPER DEVIATION FROM MEAN = 61.533 M^2

LOWER DEVIATION FROM MEAN = 54.701 M^2

SKEWNESS = 1.13

NO. OF DATA SAMPLES = 1416

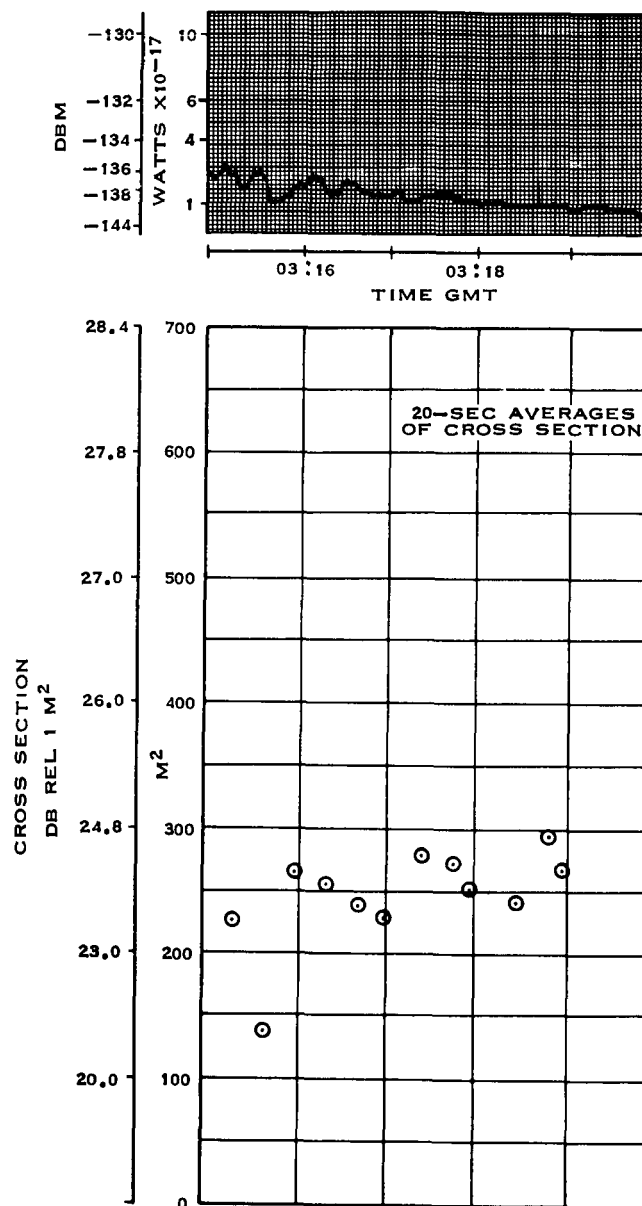


Figure 23. Pass No. 143 Data (Sheet 1 of 2)

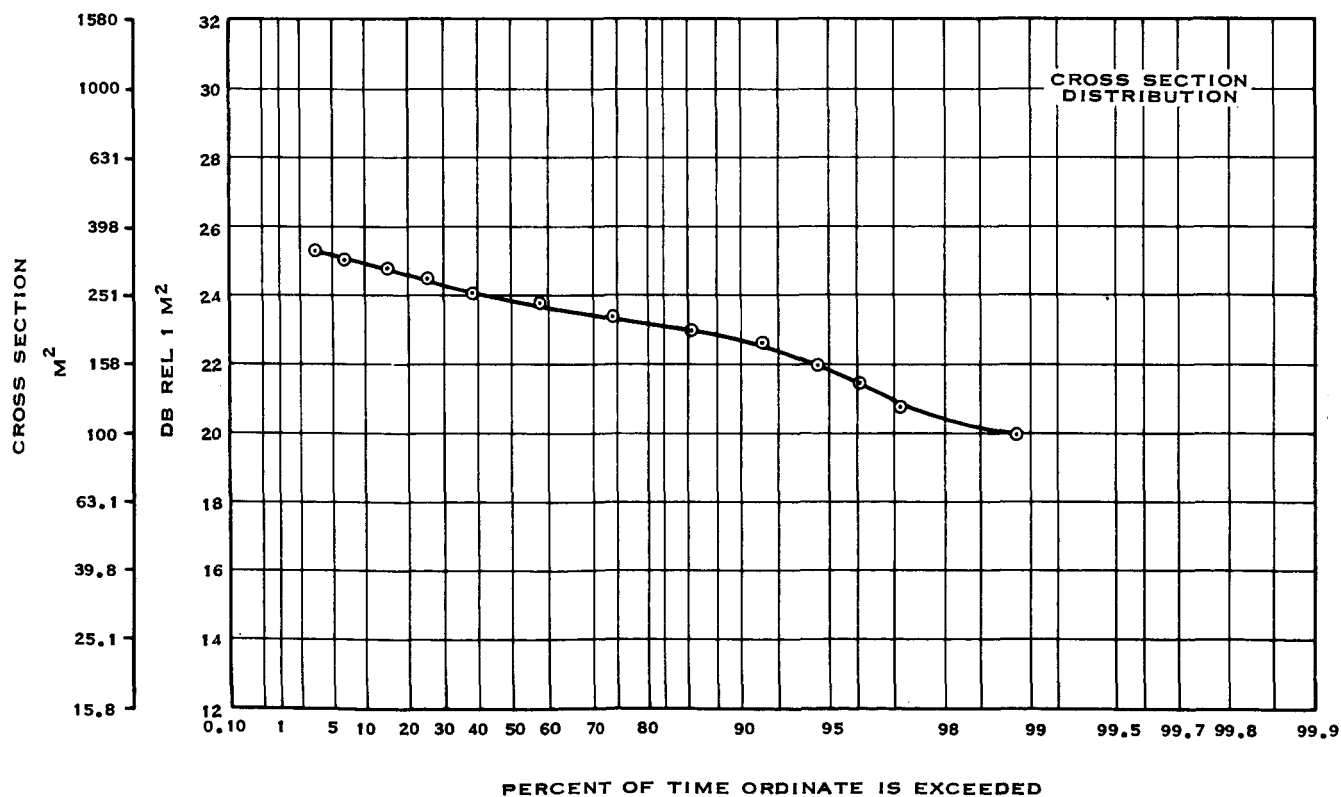
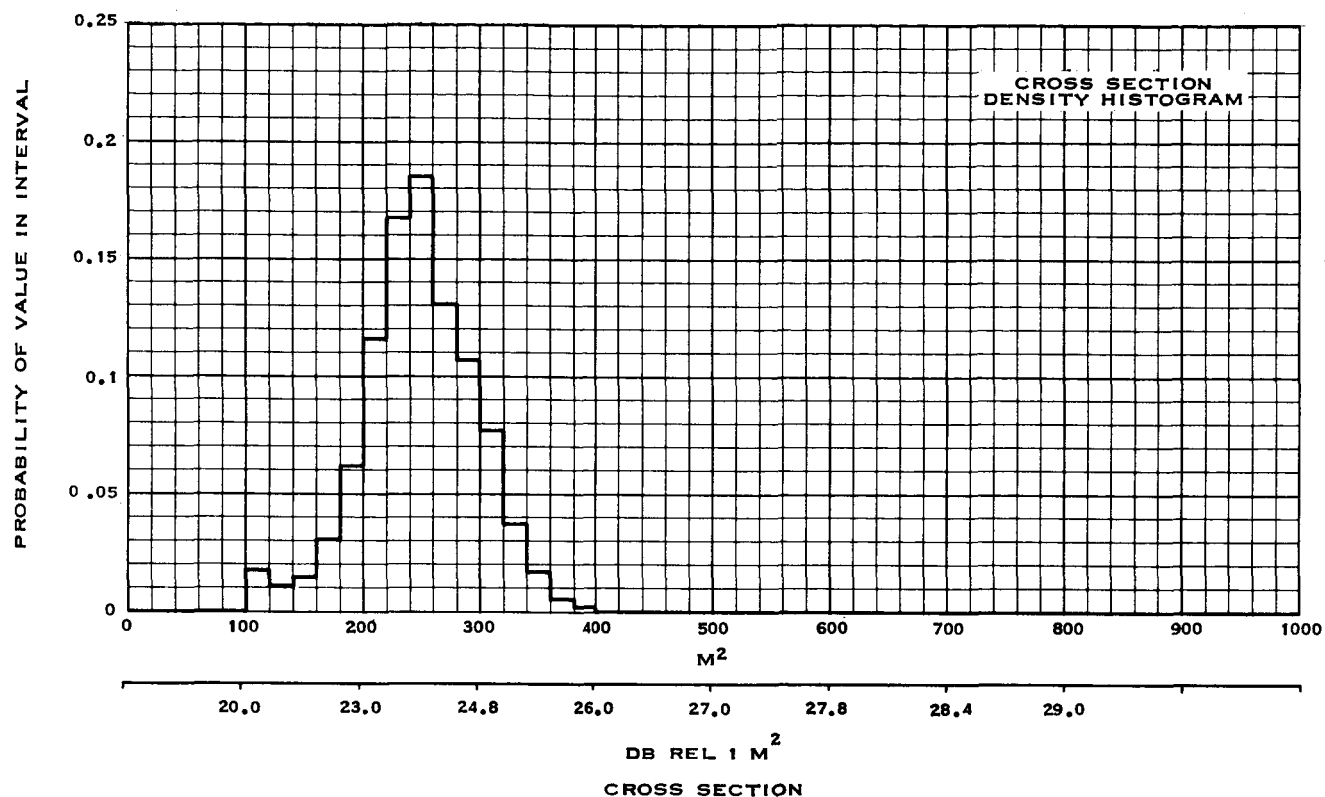


Figure 23. Pass No. 143 Data (Sheet 2 of 2)

PASS NO. 145

PASS DATE 24 AUGUST 1960

MONOSTATIC DATA

MEAN CROSS SECTION = 400.68 M²
26.04 DB REL ONE M²

MEDIAN CROSS SECTION = 355 M²
25.5 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 194.81 M²

LOWER DEVIATION FROM MEAN = 102.32 M²

SKEWNESS = 1.90

NO. OF DATA SAMPLES = 3960

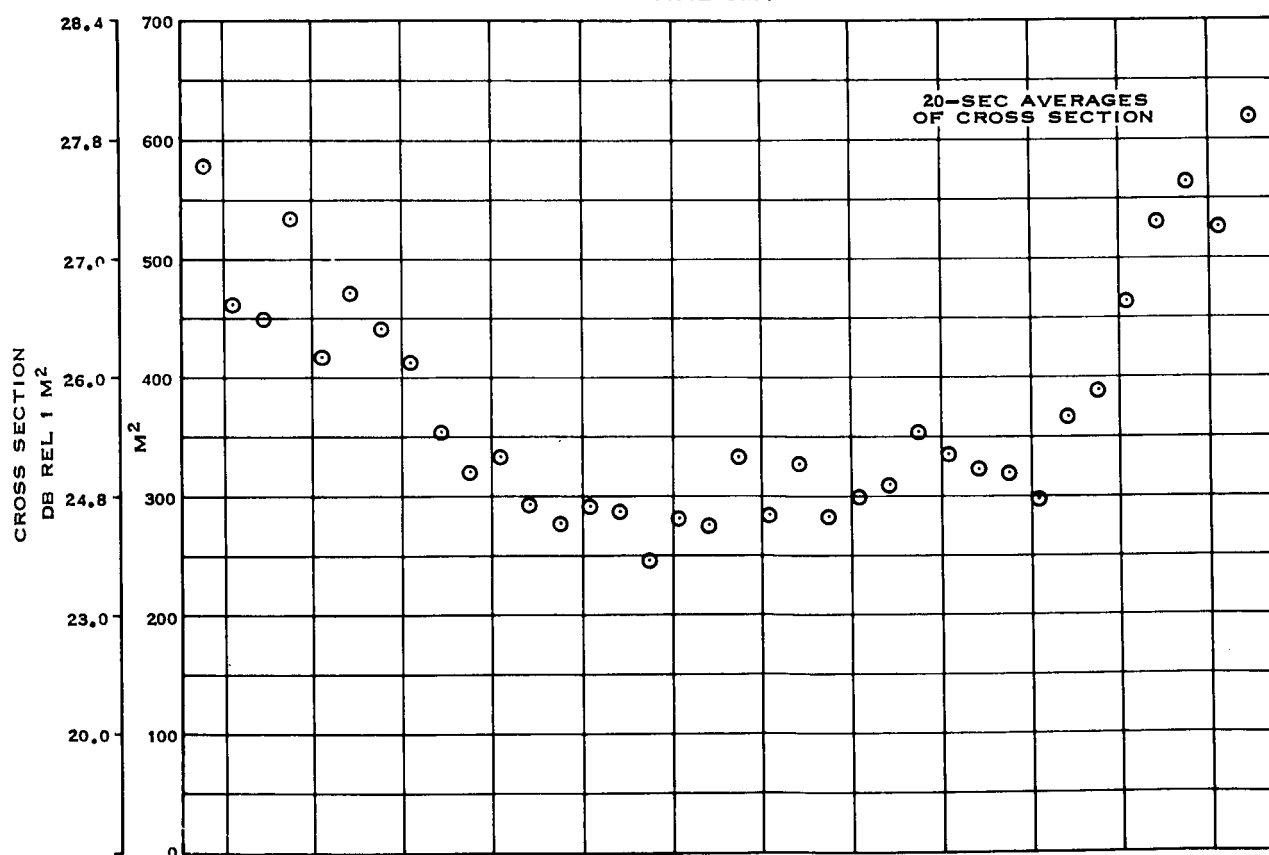
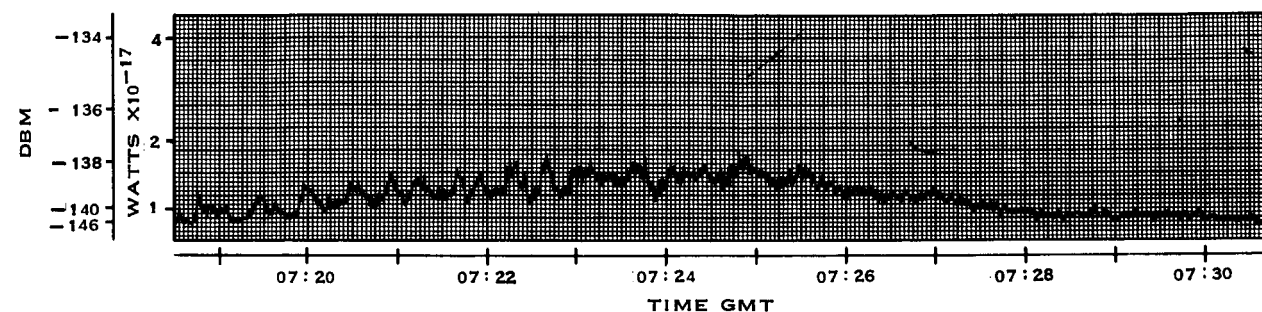


Figure 24. Pass No. 145 Data (Sheet 1 of 2)

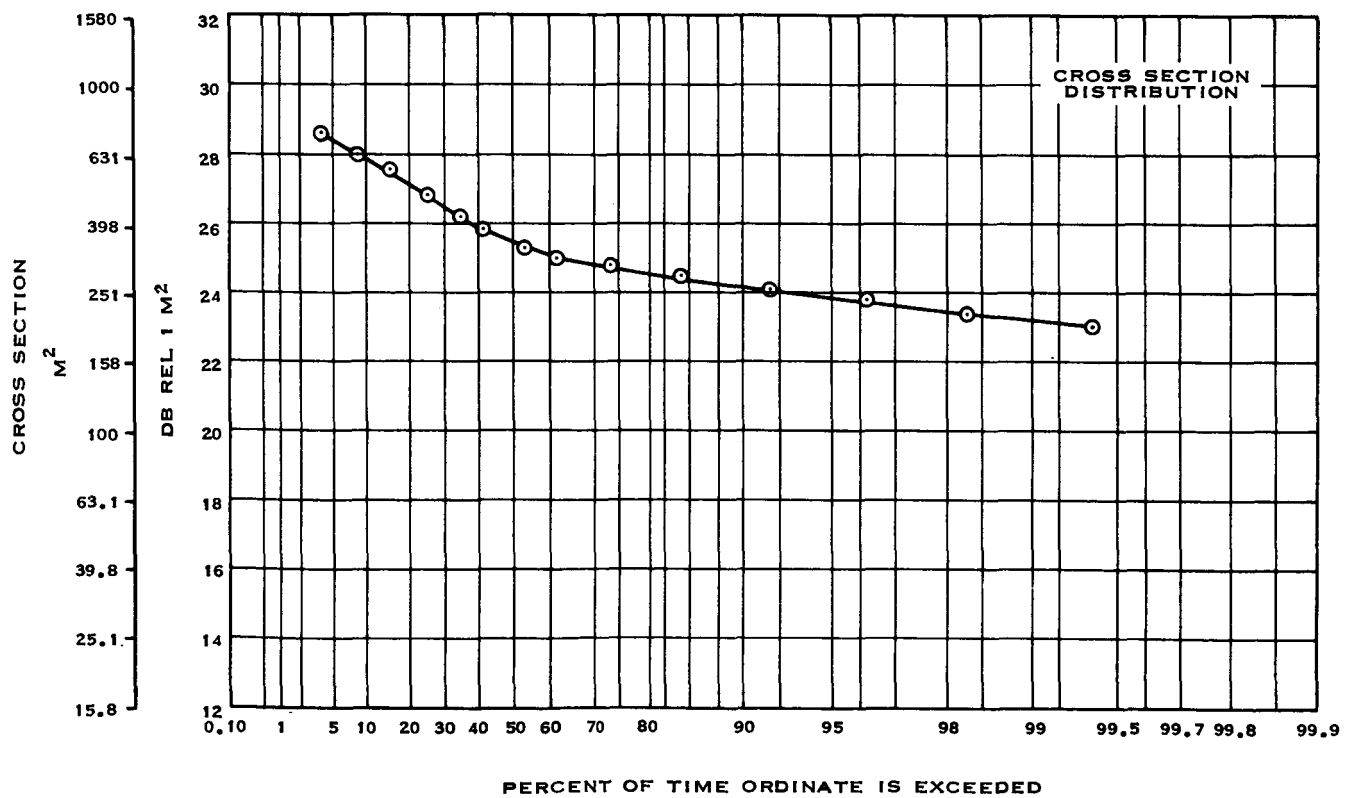
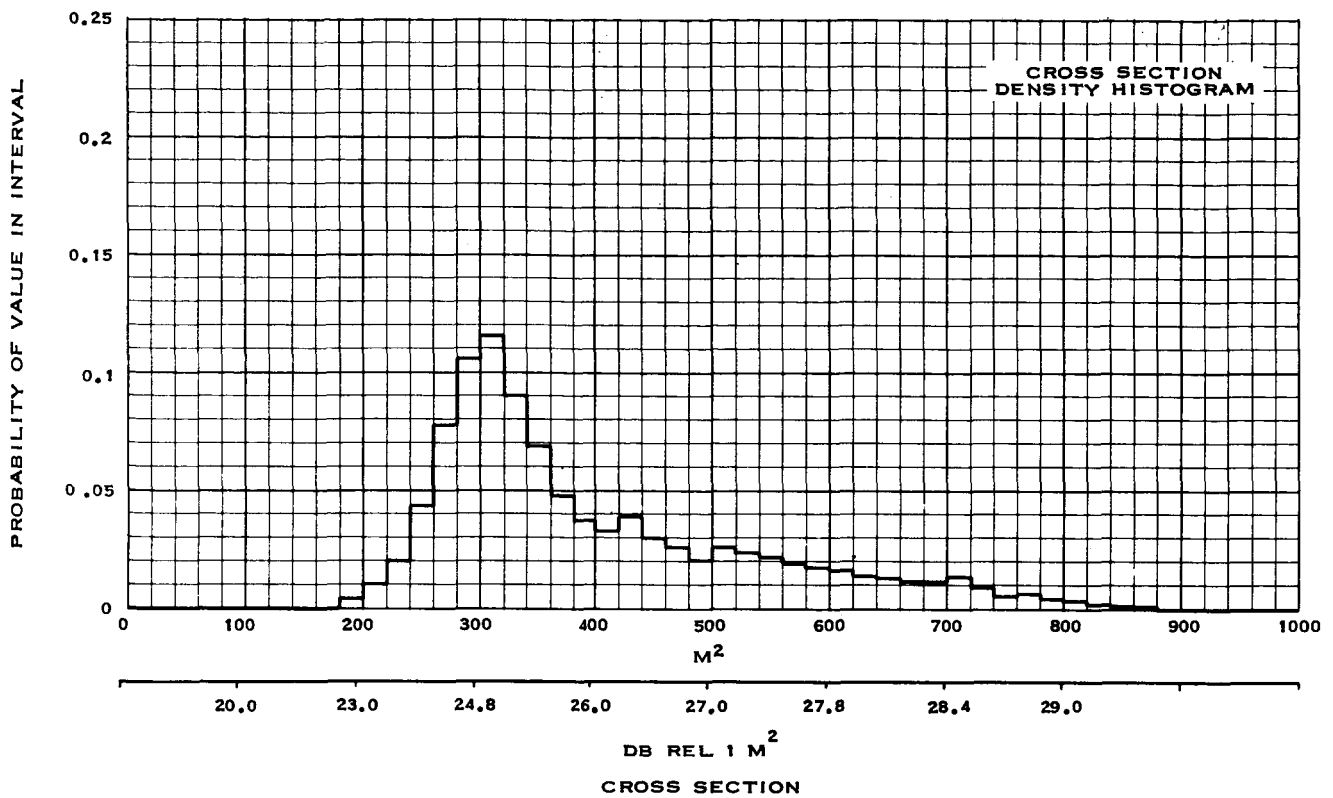


Figure 24. Pass No. 145 Data (Sheet 2 of 2)

PASS NO. 168

PASS DATE 26 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = 179.38 M^2
22.54 DB REL ONE M^2

MEDIAN CROSS SECTION = 174 M^2
22.4 DB REL ONE M^2

UPPER DEVIATION FROM MEAN = 68.222 M^2

LOWER DEVIATION FROM MEAN = 44.418 M^2

SKEWNESS = 1.54

NO. OF DATA SAMPLES = 3211

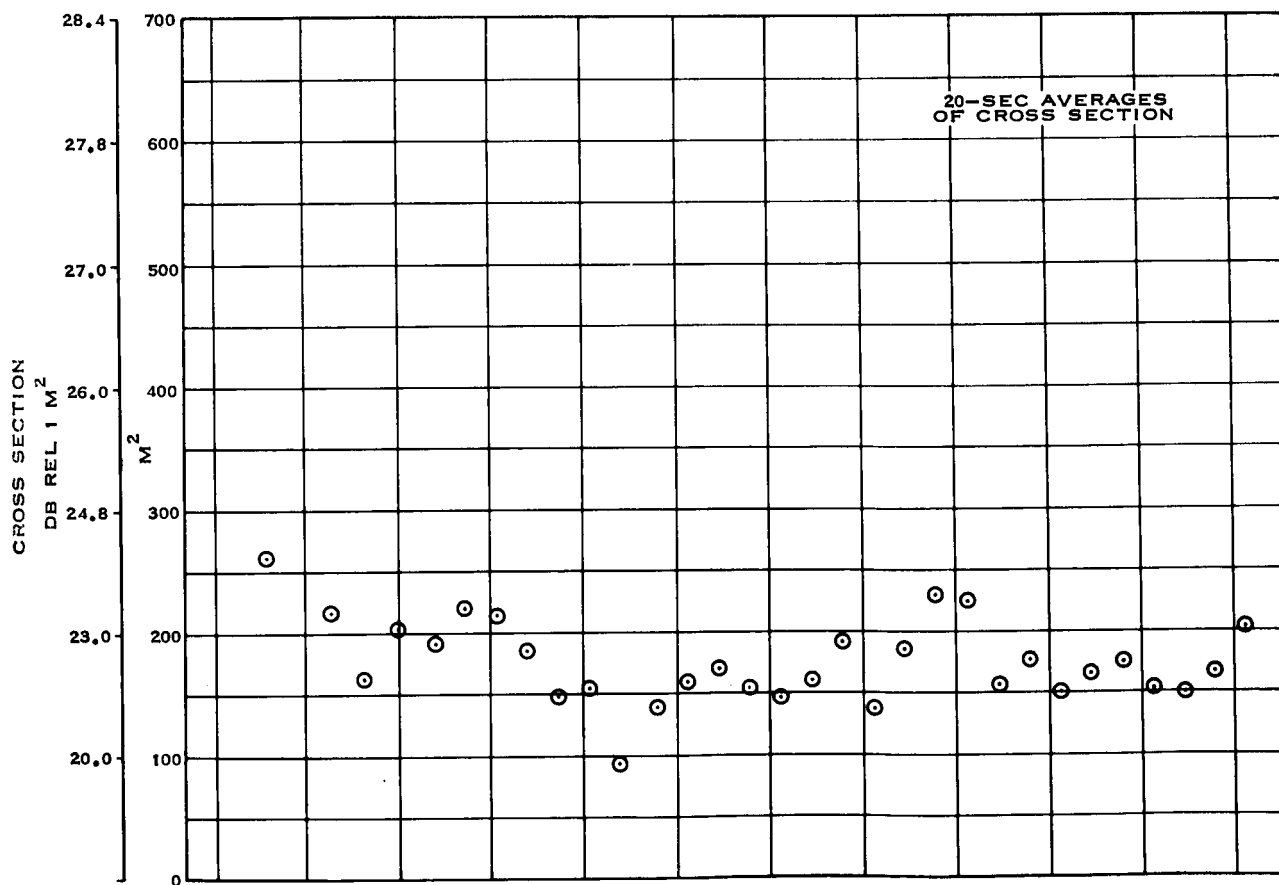
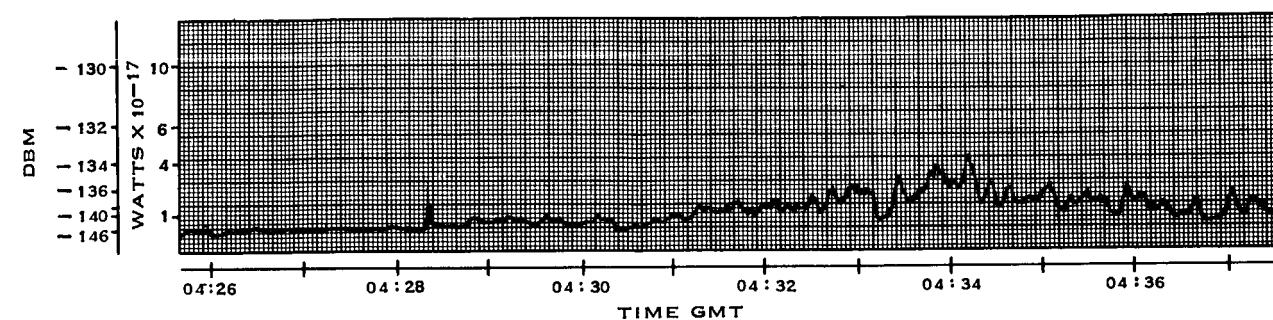


Figure 25. Pass No. 168 Data (Sheet 1 of 2)

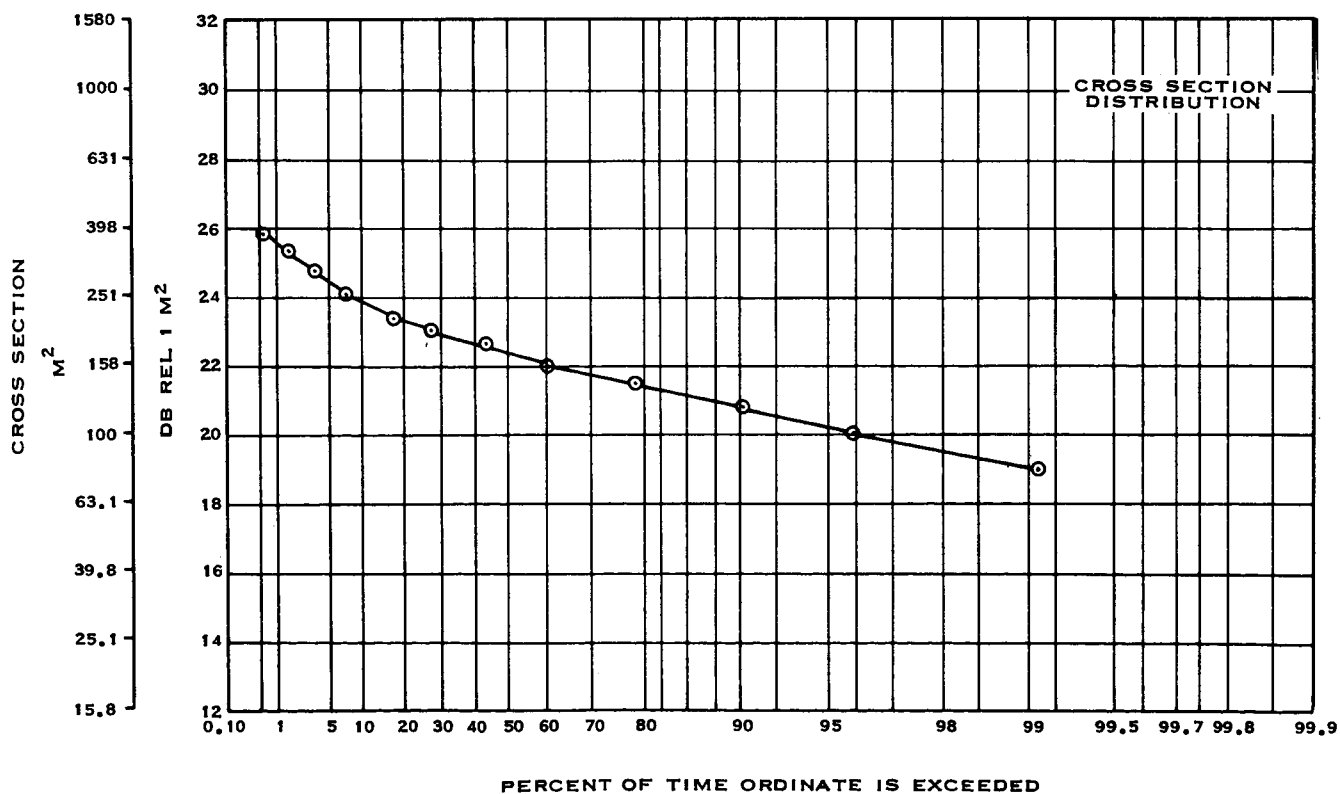
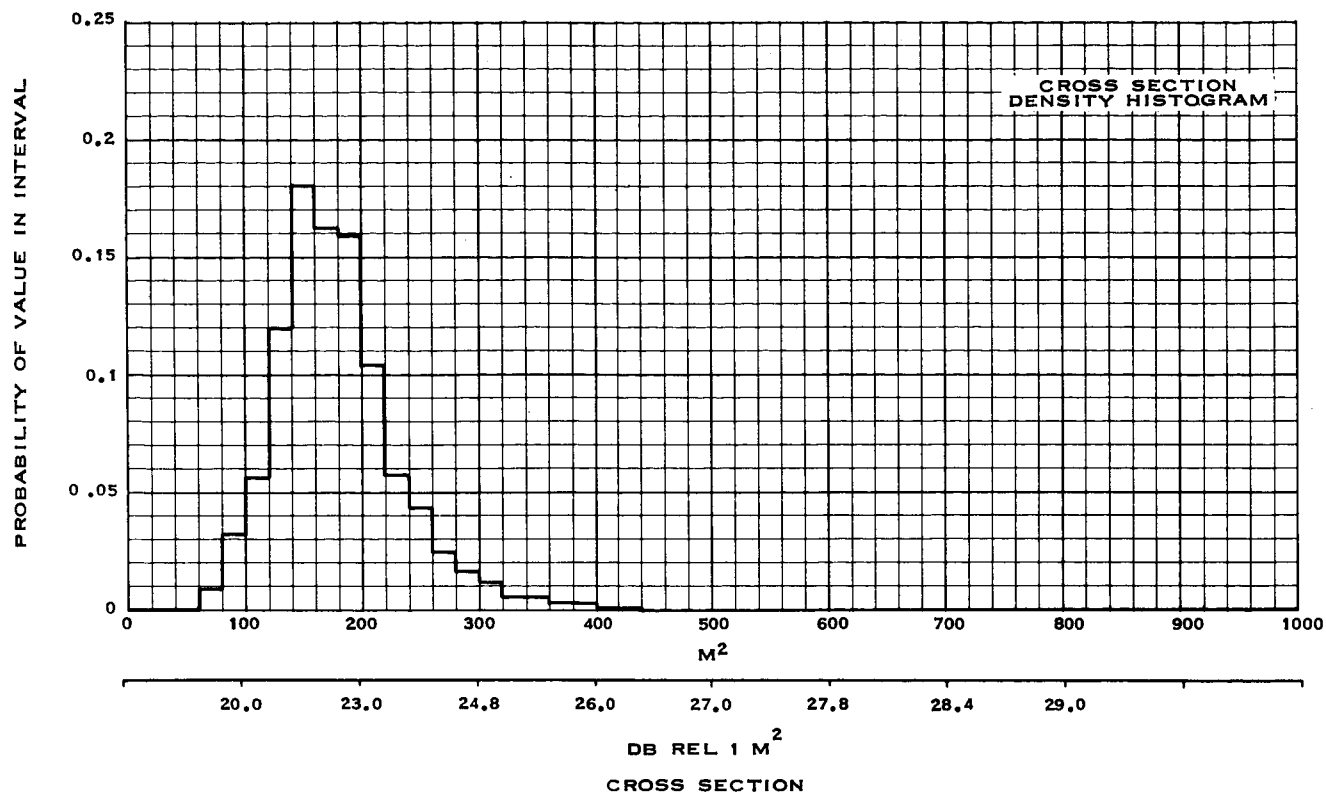


Figure 25. Pass No. 168 Data (Sheet 2 of 2)

PASS NO. 180

PASS DATE 27 AUGUST 1960

BISTATIC DATA

MEAN CROSS SECTION = 467.85 M²
26.70 DB REL ONE M²

MEDIAN CROSS SECTION = 457 M²
26.6 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 140.27 M²

LOWER DEVIATION FROM MEAN = 119.29 M²

SKEWNESS = 1.18

NO. OF DATA SAMPLES = 4338

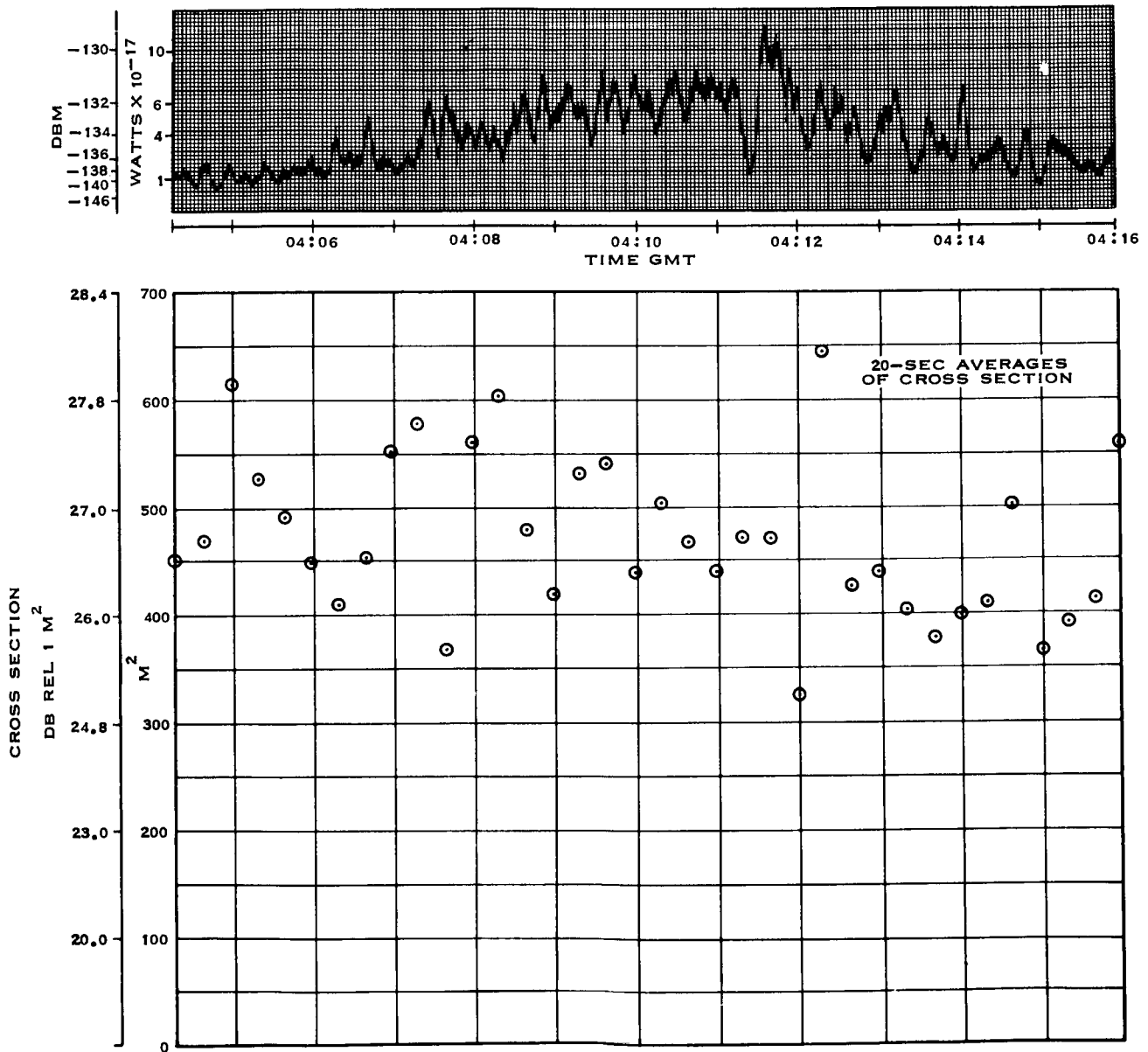


Figure 26. Pass No. 180 Data (Sheet 1 of 2)

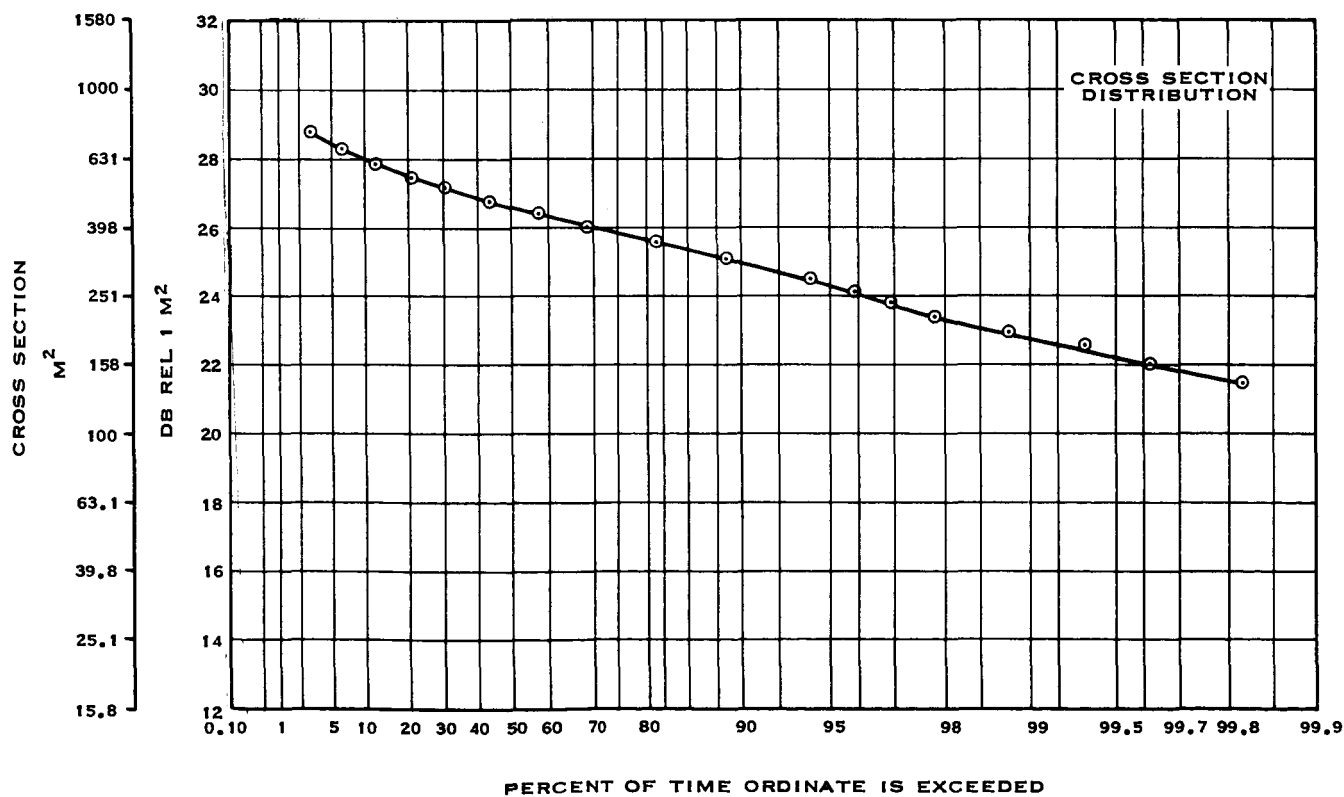
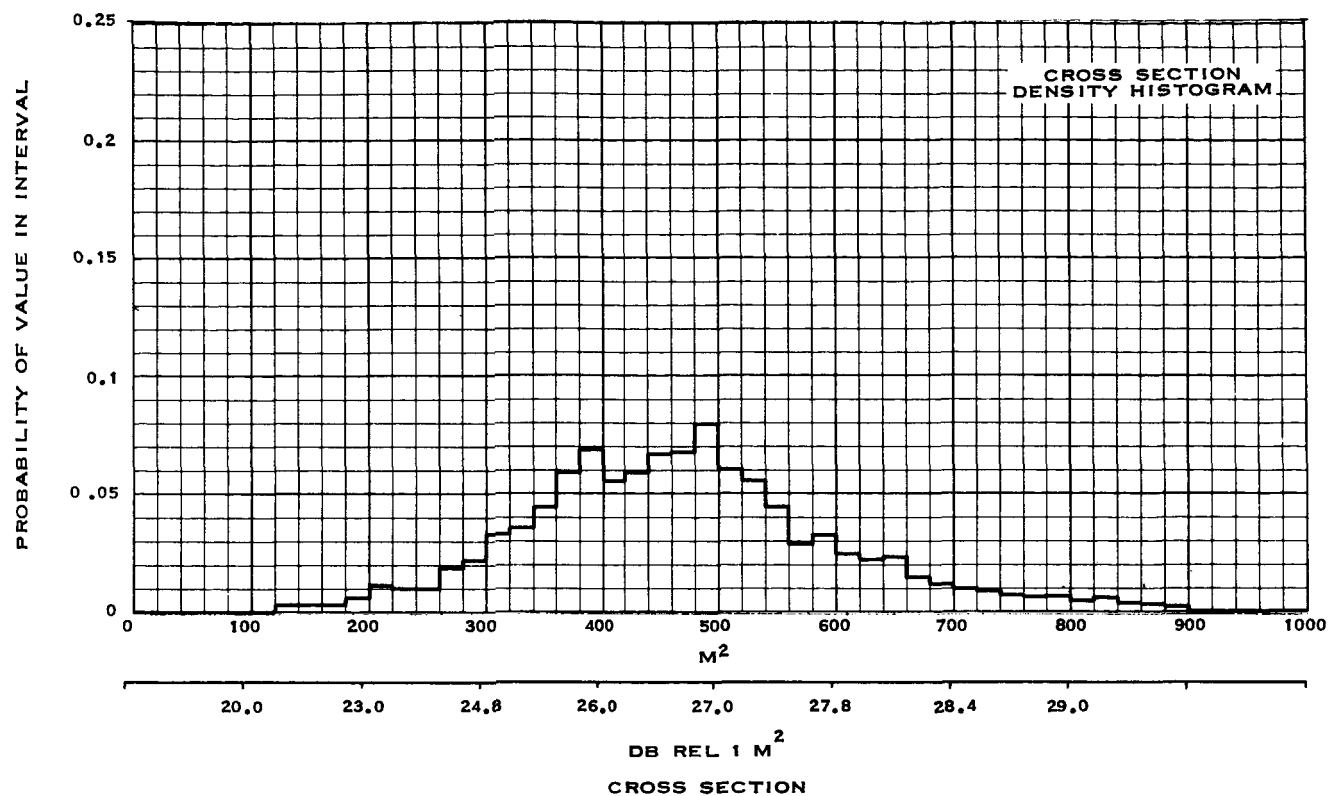


Figure 26. Pass No. 180 Data (Sheet 2 of 2)

PASS NO. 240

PASS DATE 1 SEPTEMBER 1960

BISTATIC DATA

MEAN CROSS SECTION = 239.24 M²
23.78 DB REL ONE M²

MEDIAN CROSS SECTION = 229 M²
23.6 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 86.882 M²

LOWER DEVIATION FROM MEAN = 67.669 M²

SKEWNESS = 1.28

NO. OF DATA SAMPLES = 4844

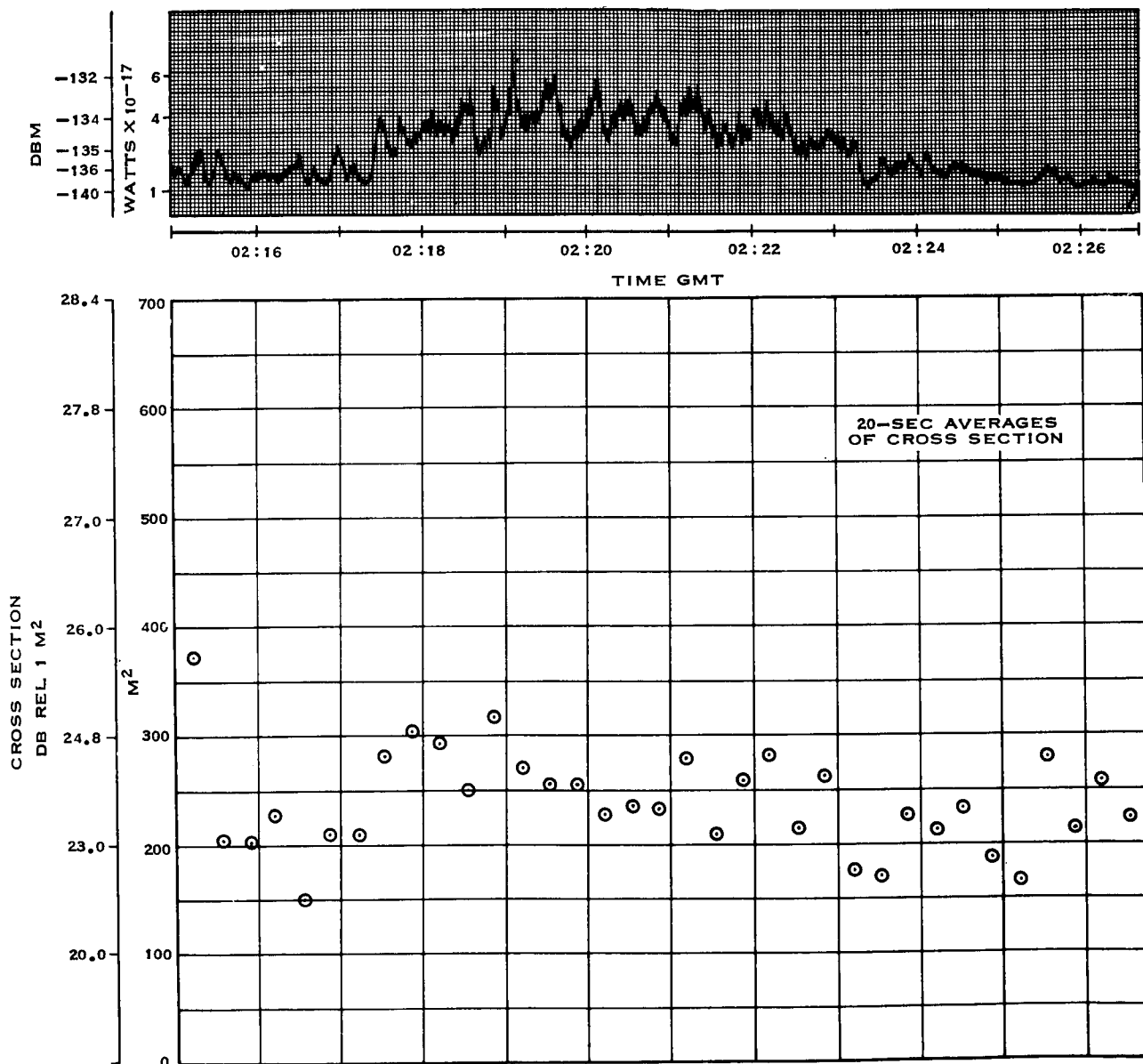


Figure 27. Pass No. 240 Data (Sheet 1 of 2)

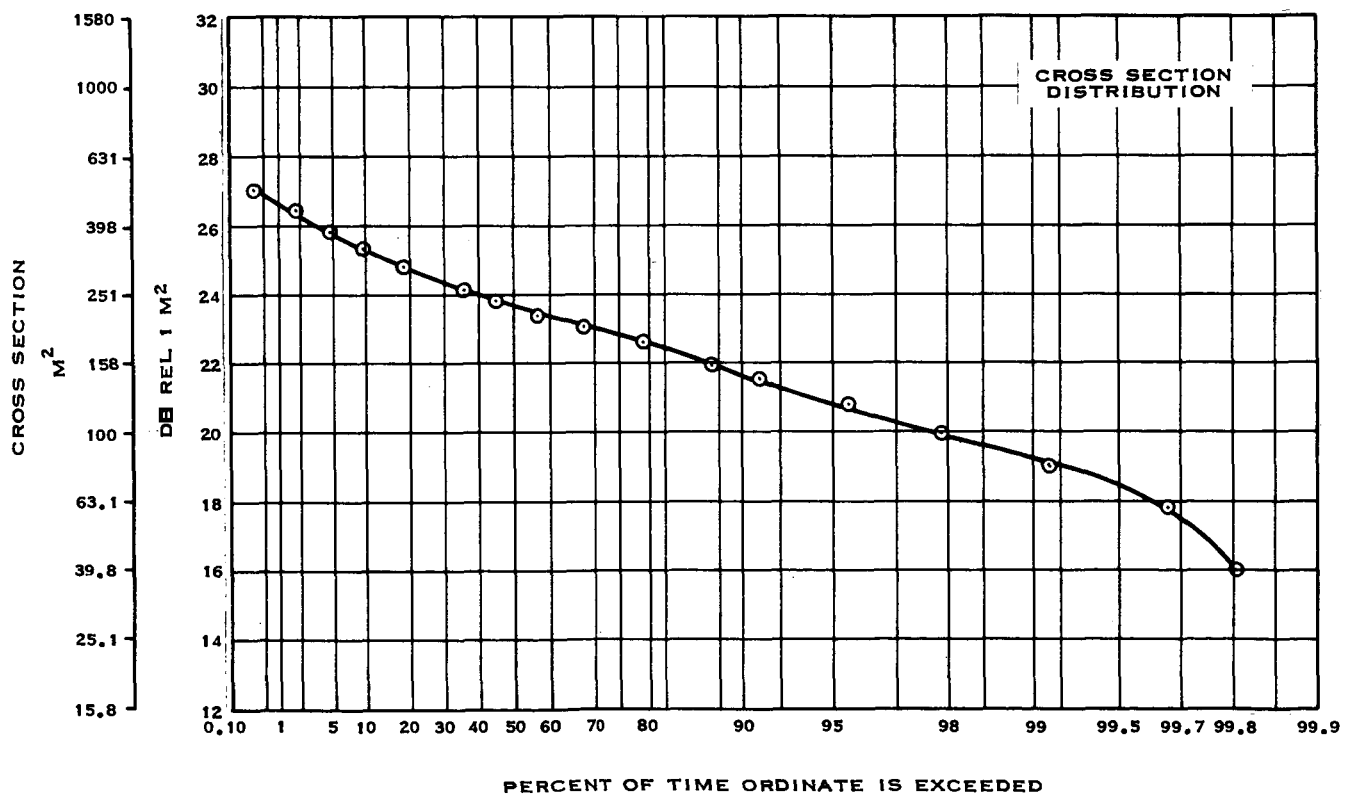
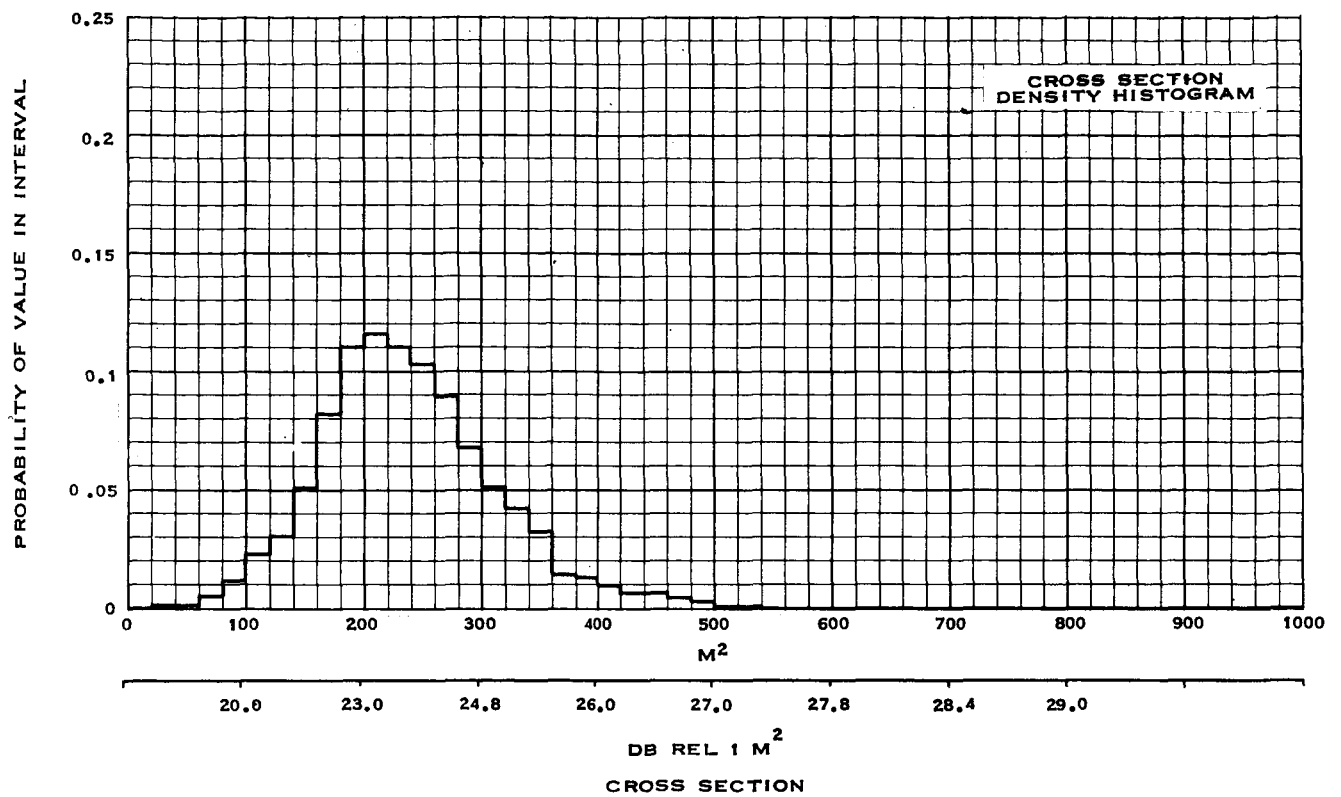


Figure 27. Pass No. 240 Data (Sheet 2 of 2)

PASS NO. 325

PASS DATE 8 SEPTEMBER 1960

BISTATIC DATA

MEAN CROSS SECTION = 349.51 M^2
25.44 DB REL ONE M^2

MEDIAN CROSS SECTION = 331 M^2
25.2 DB REL ONE M^2

UPPER DEVIATION FROM MEAN = 139.11 M^2

LOWER DEVIATION FROM MEAN = 102.61 M^2

SKEWNESS = 1.36

NO. OF DATA SAMPLES = 4754

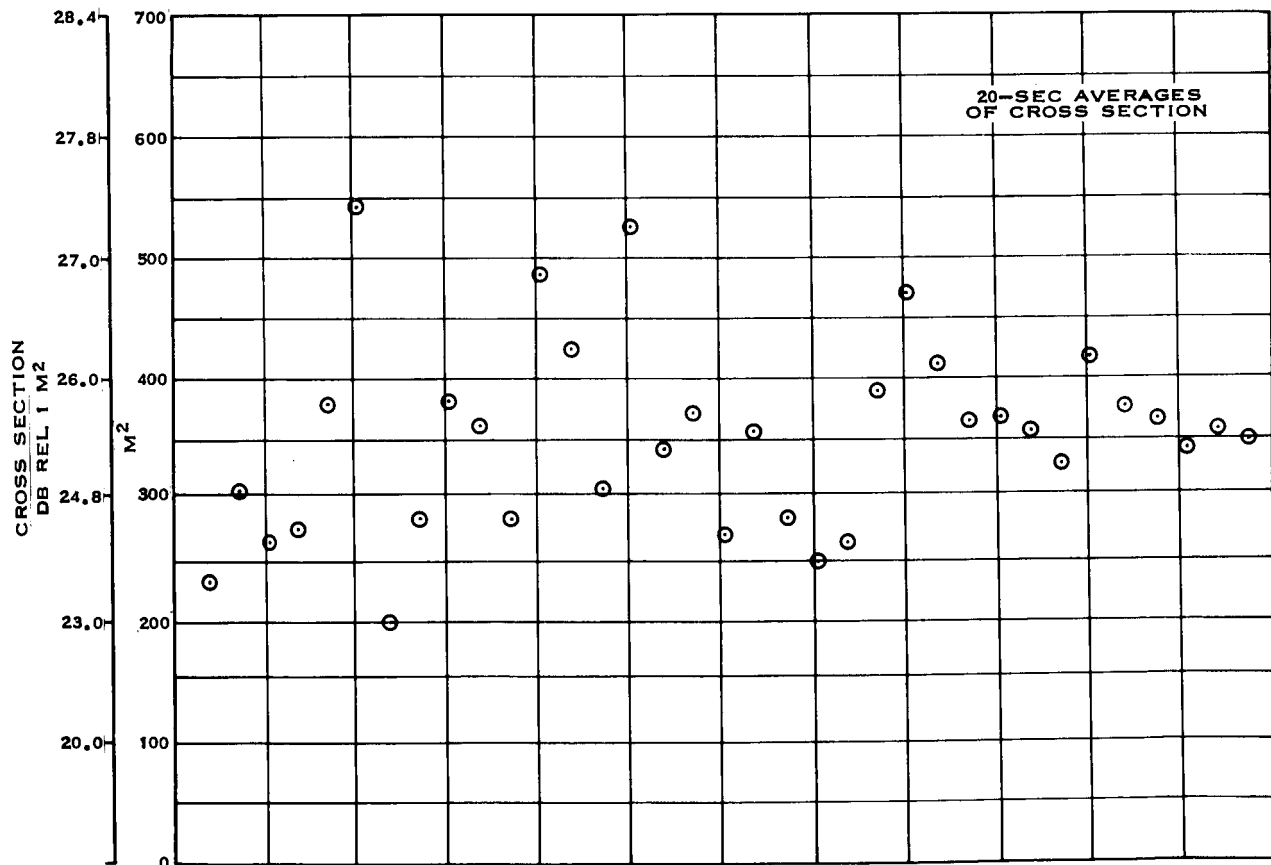
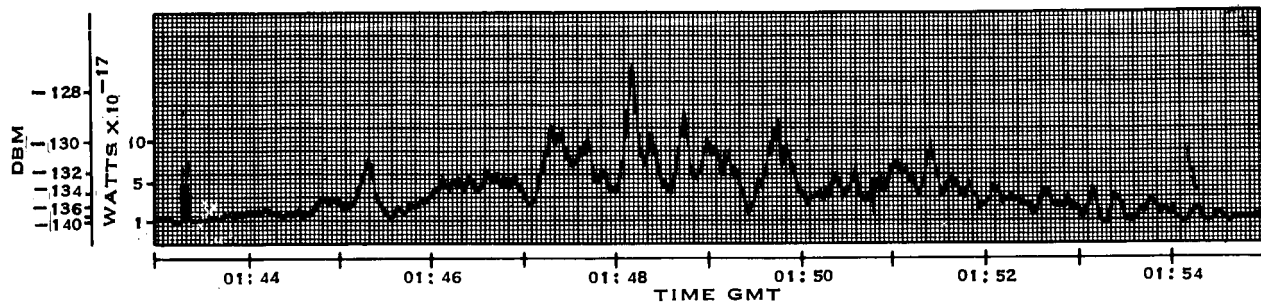


Figure 28. Pass No. 325 Data (Sheet 1 of 2)

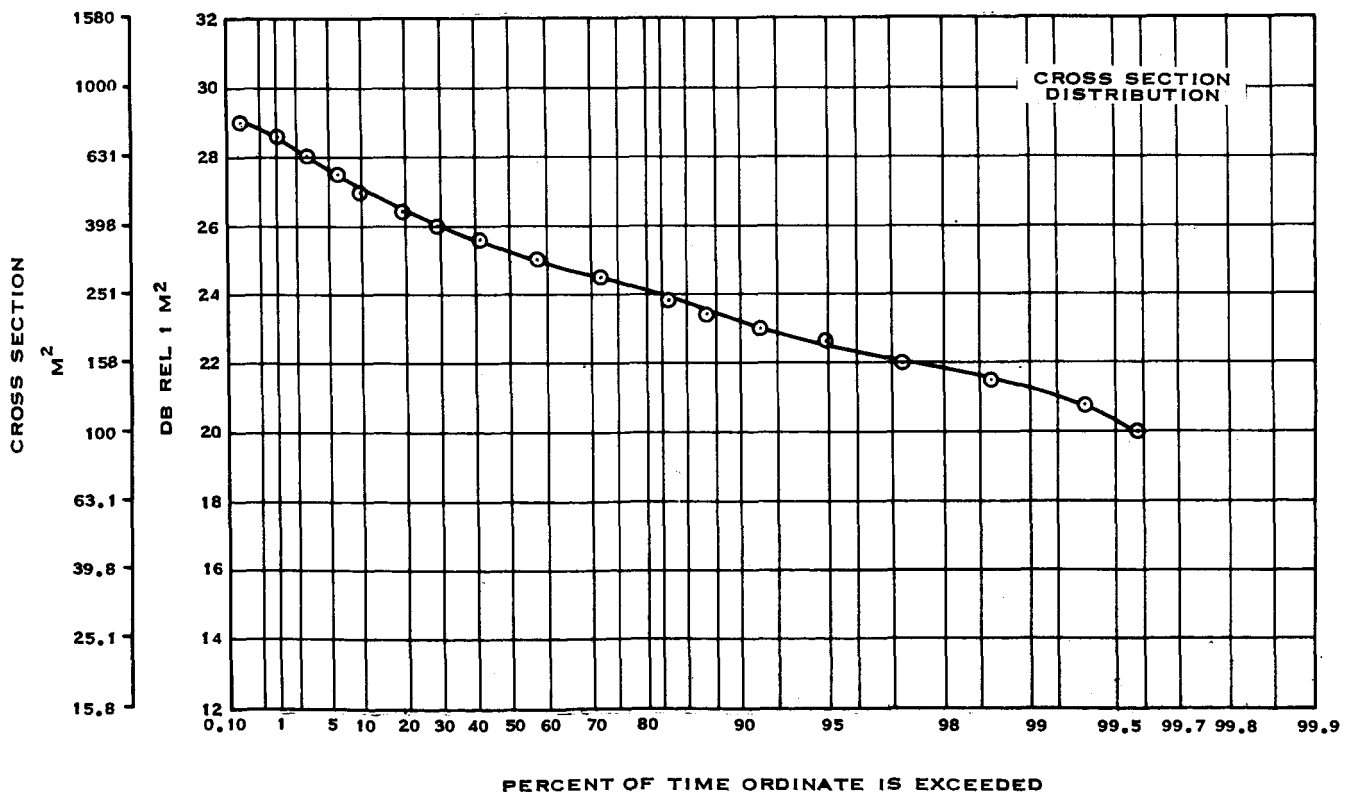
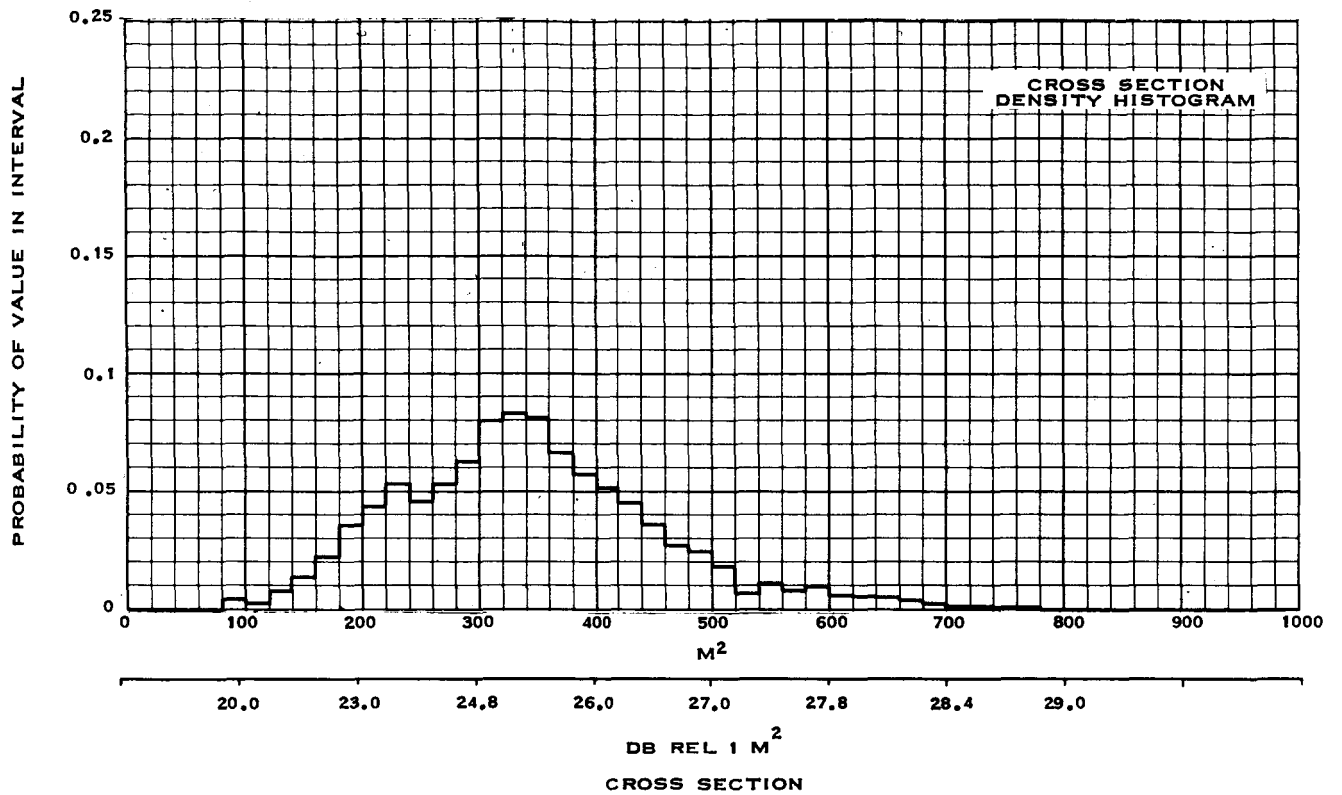


Figure 28. Pass No. 325 Data (Sheet 2 of 2)

PASS NO. 2483

PASS DATE 3 MARCH 1961

MONOSTATIC DATA

MEAN CROSS SECTION = 112.46 M^2
20.47 DB REL ONE M^2

MEDIAN CROSS SECTION = 95.5 M^2
19.8 DB REL ONE M^2

UPPER DEVIATION FROM MEAN = 107.91 M^2

LOWER DEVIATION FROM MEAN = 46.217 M^2

SKEWNESS = 2.33

NO. OF DATA SAMPLES = 2745

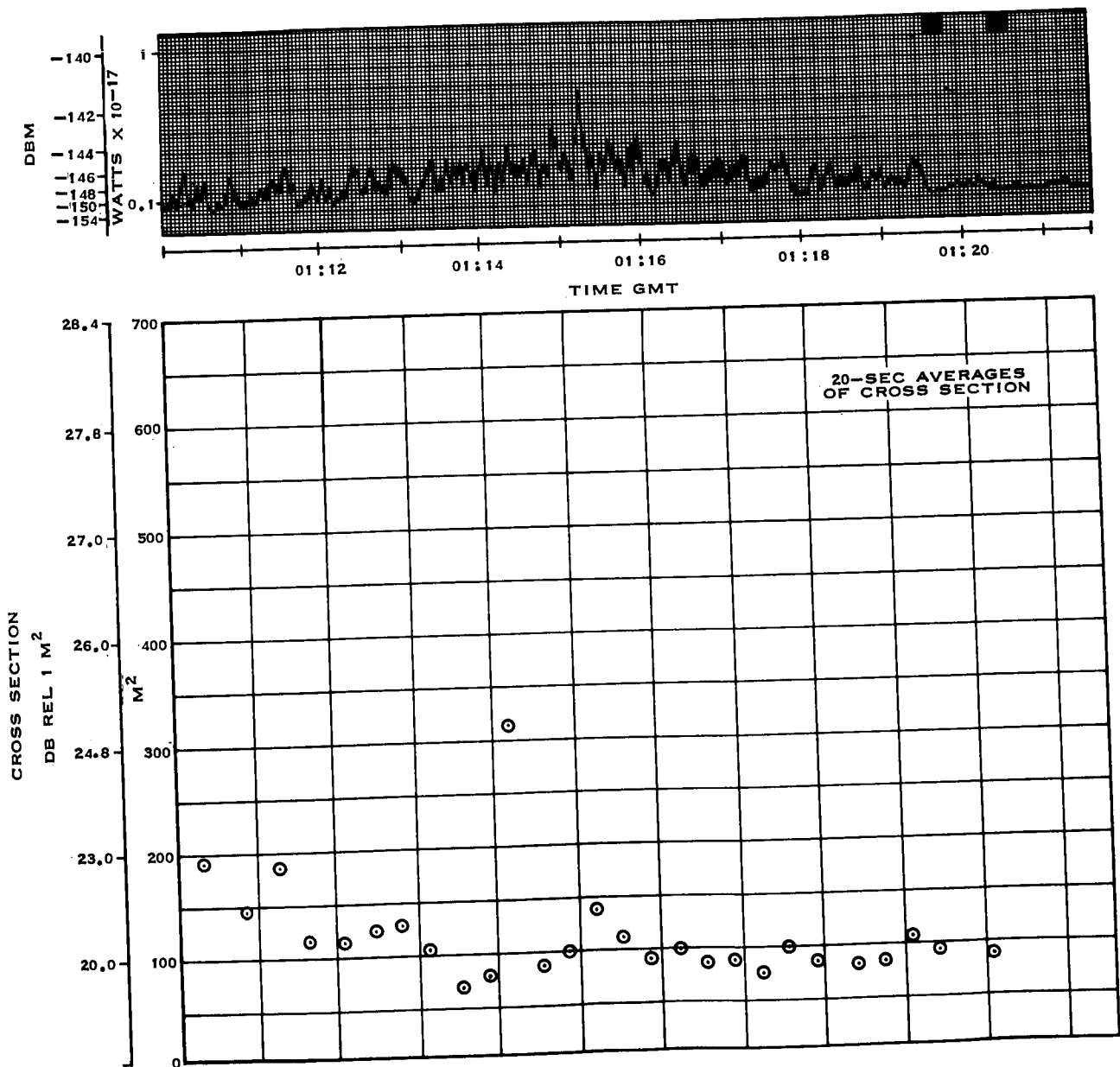


Figure 29. Pass No. 2483 Data (Sheet 1 of 2)

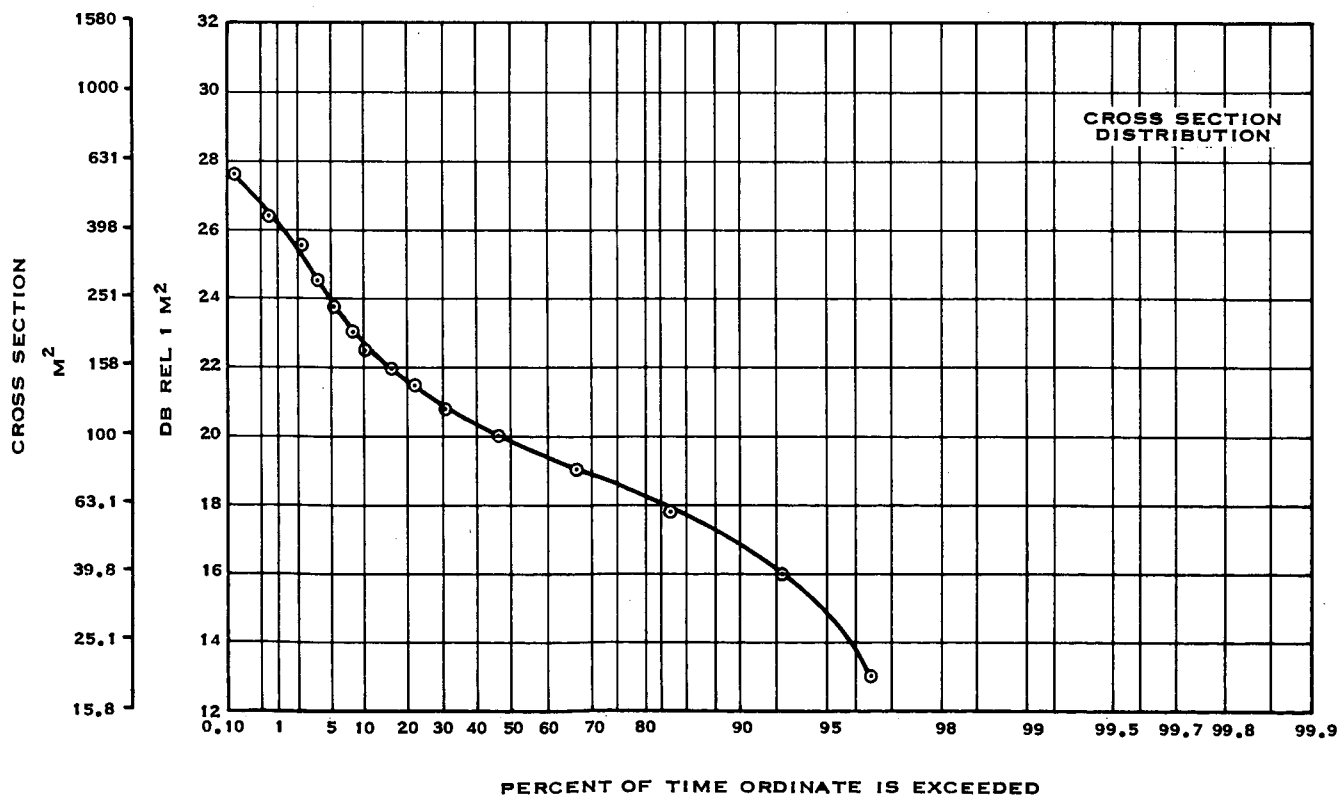
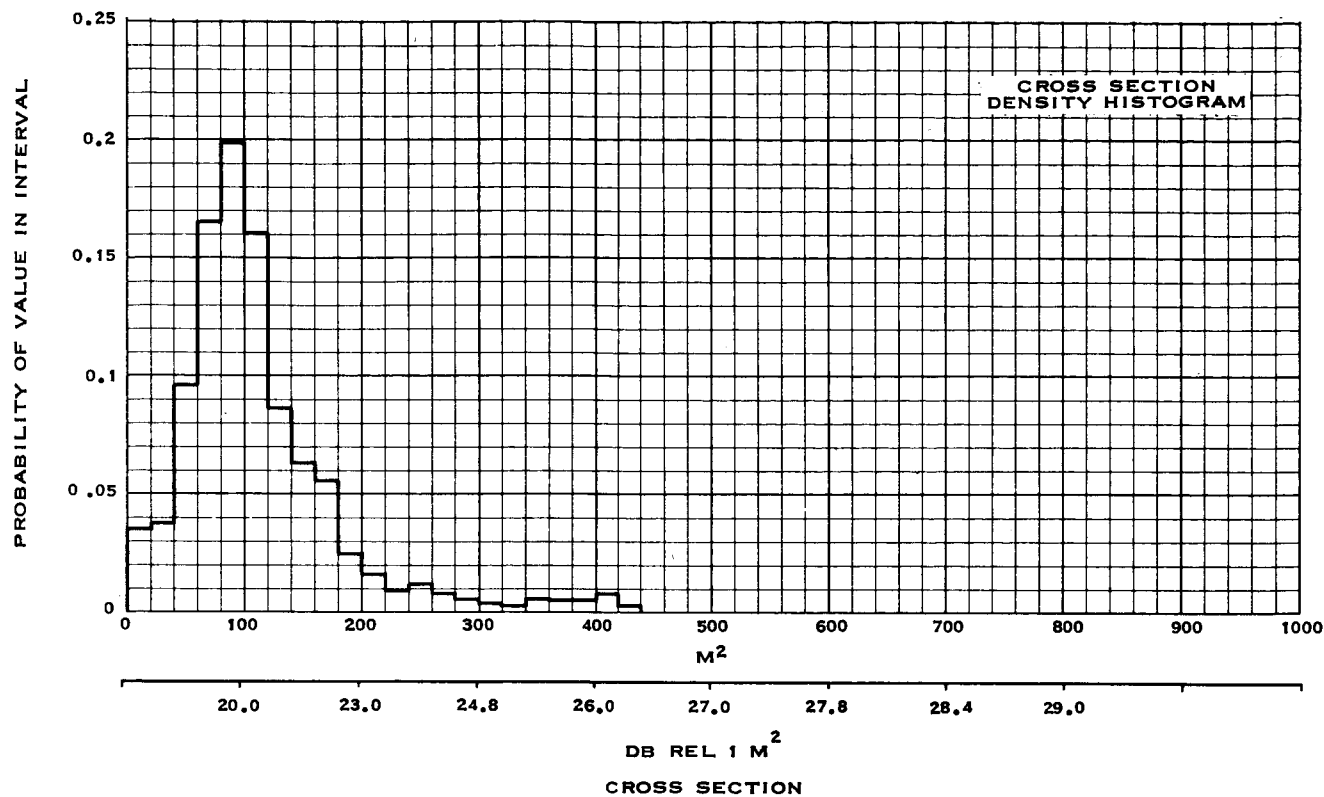


Figure 29. Pass No. 2483 Data (Sheet 2 of 2)

PASS NO. 4368

PASS DATE 3 AUGUST 1961

MONOSTATIC DATA

MEAN CROSS SECTION = 349.98 M²
25.44 DB REL ONE M²

MEDIAN CROSS SECTION = 309 M²
24.9 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 239.06 M²

LOWER DEVIATION FROM MEAN = 156.50 M²

SKEWNESS = 1.52

NO. OF DATA SAMPLES = 2934

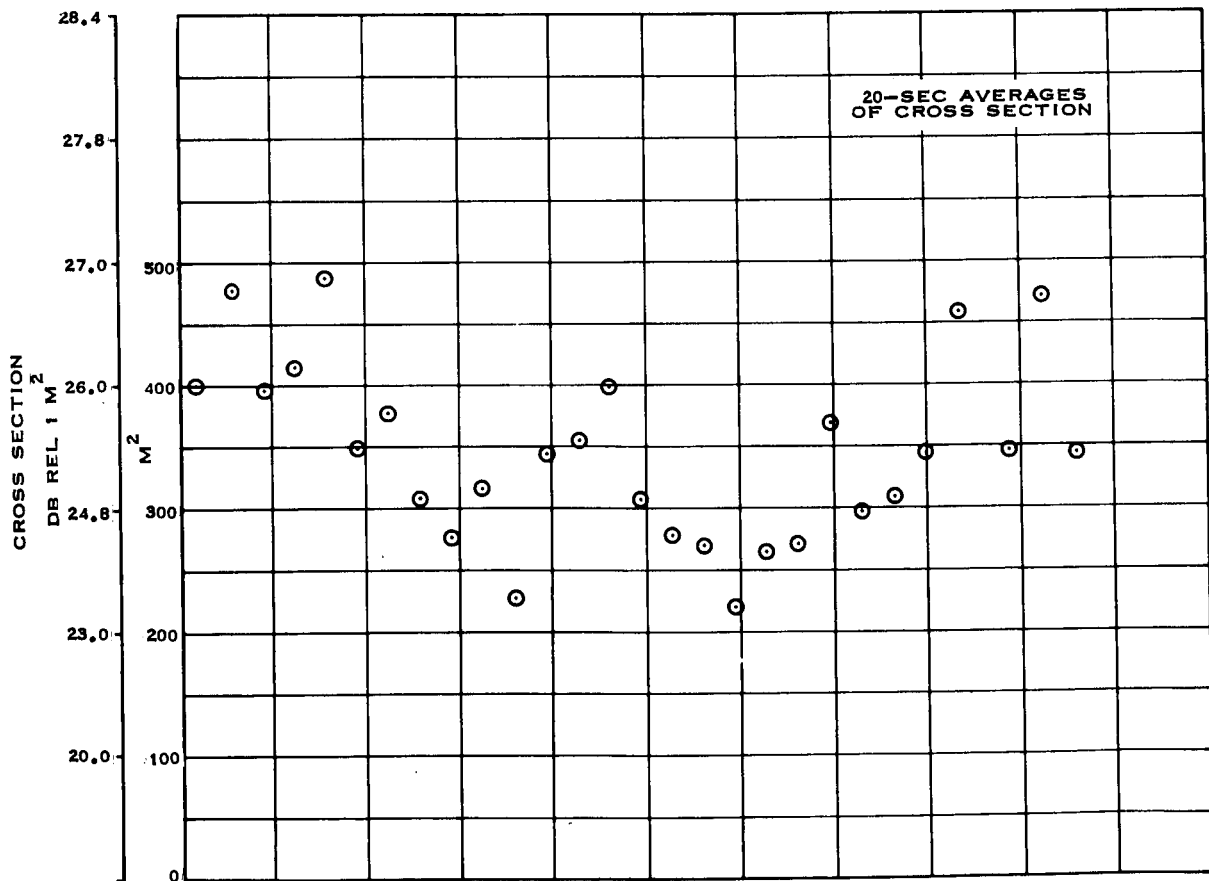
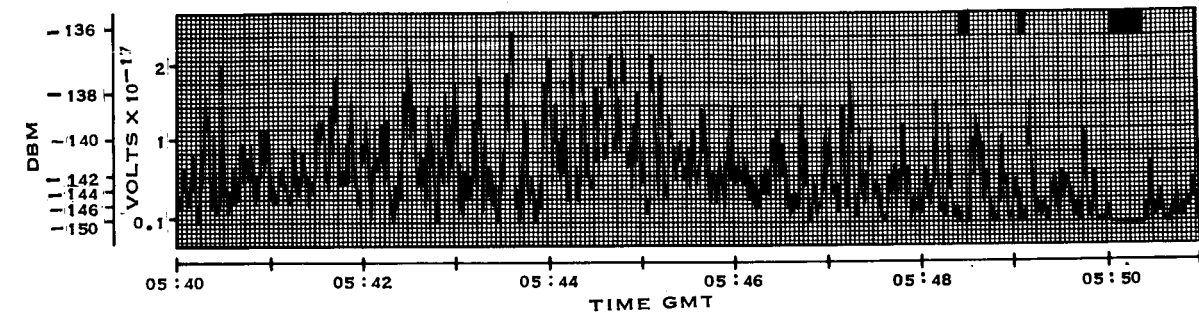


Figure 30. Pass No. 4368 Data (Sheet 1 of 2)

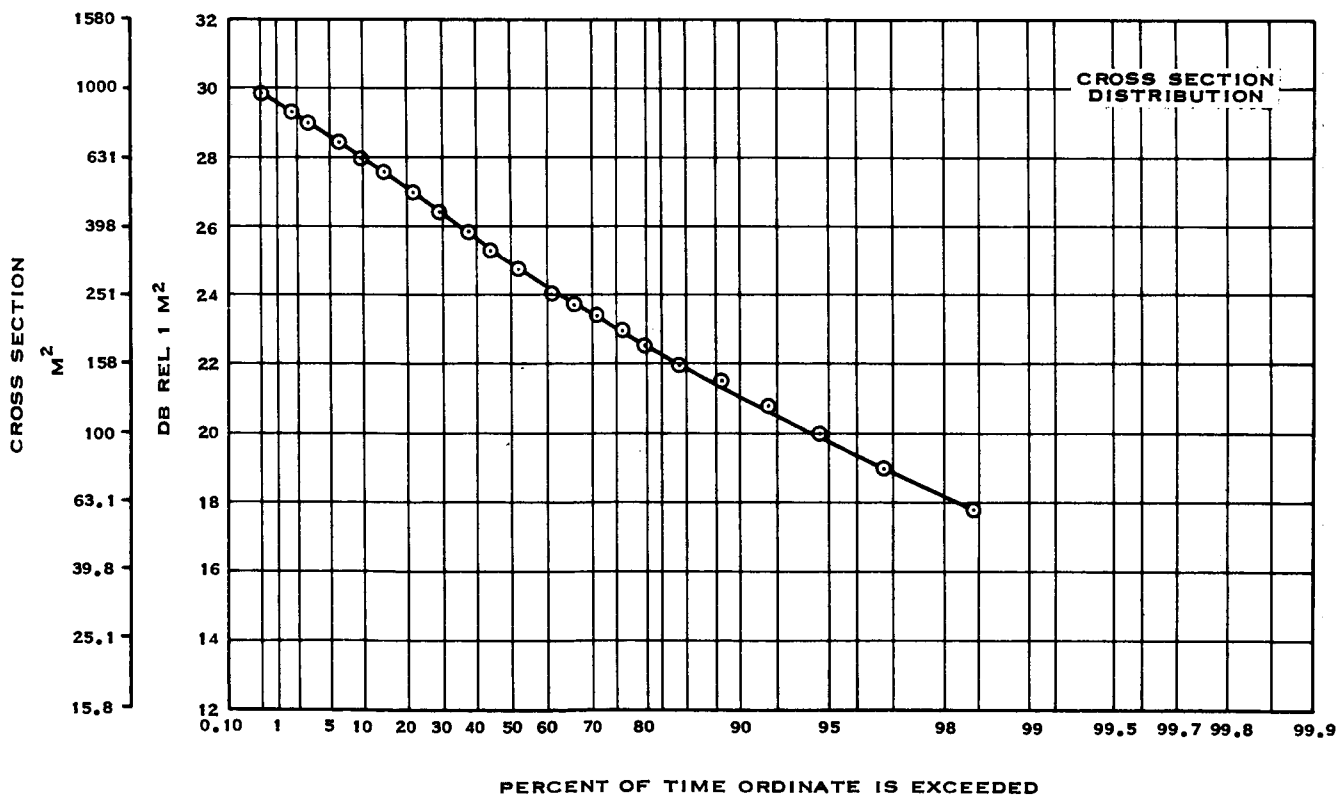
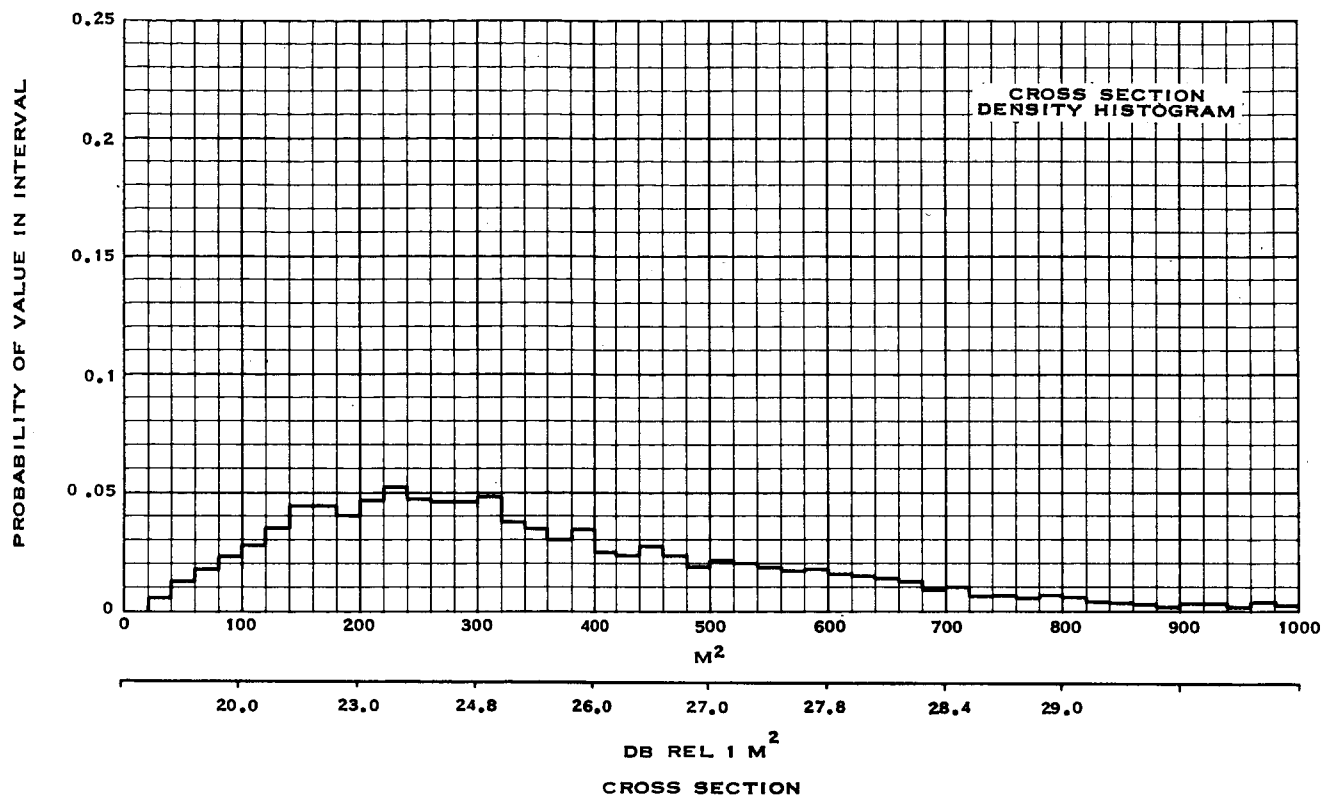


Figure 30. Pass No. 4368 Data (Sheet 2 of 2)

PASS NO. 4942

PASS DATE 18 SEPTEMBER 1961

MONOSTATIC DATA

MEAN CROSS SECTION = 335.49 M²
25.25 DB REL ONE M²

MEDIAN CROSS SECTION = 295 M²
24.7 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 257.69 M²

LOWER DEVIATION FROM MEAN = 167.00 M²

SKEWNESS = 1.54

NO. OF DATA SAMPLES = 3186

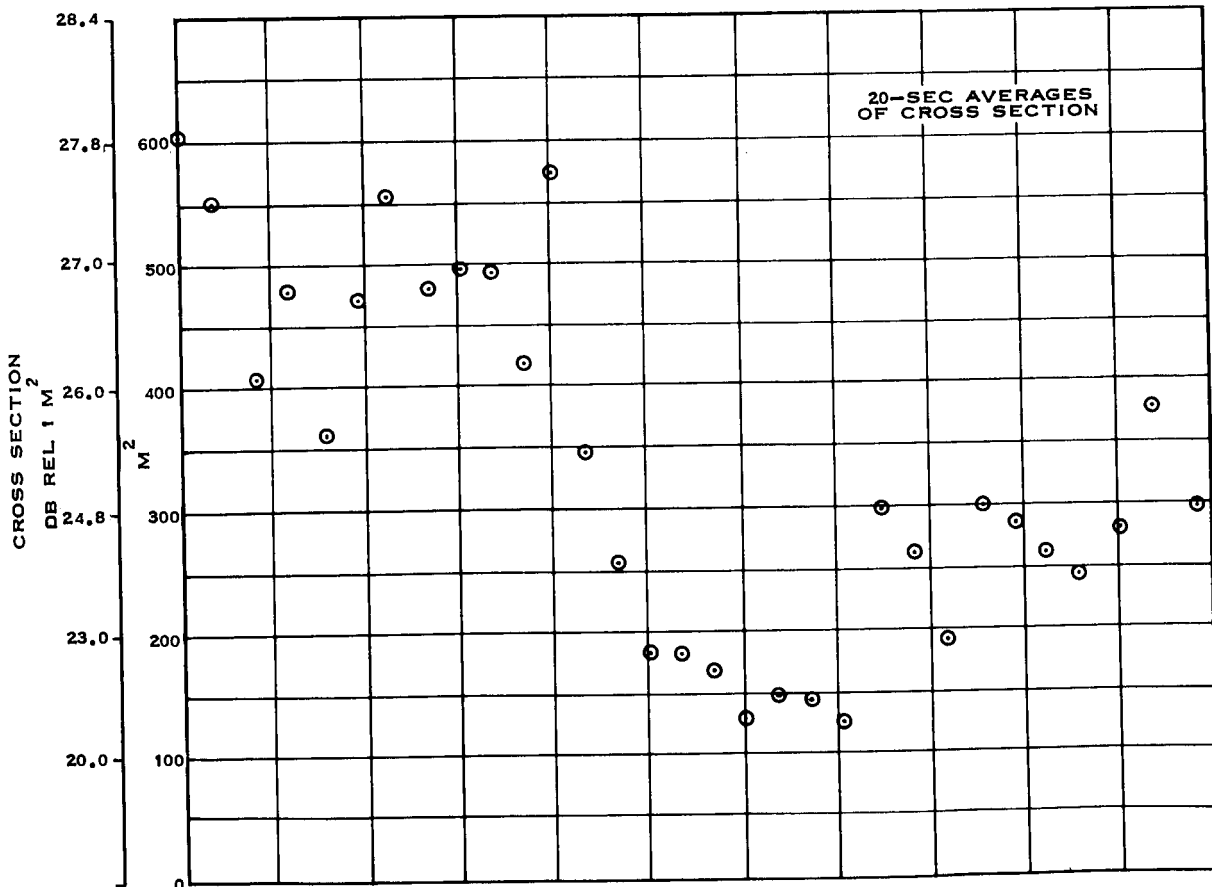
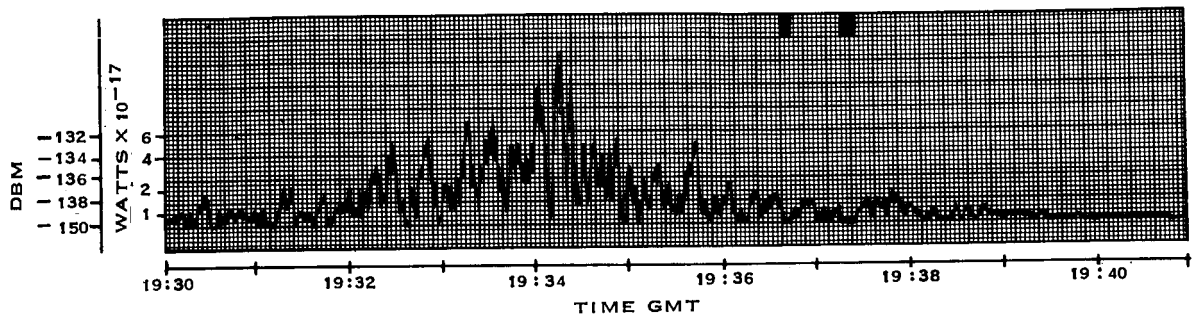


Figure 31. Pass No. 4942 Data (Sheet 1 of 2)

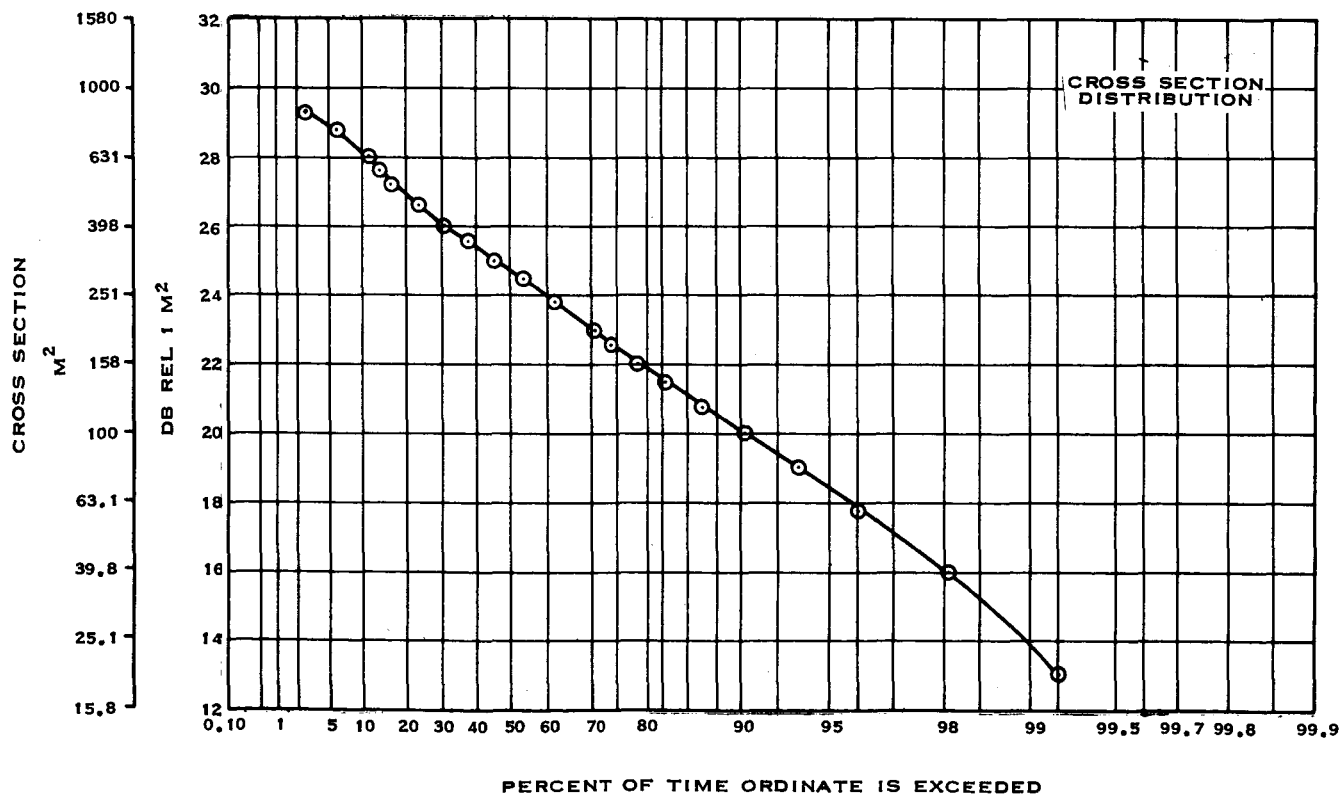
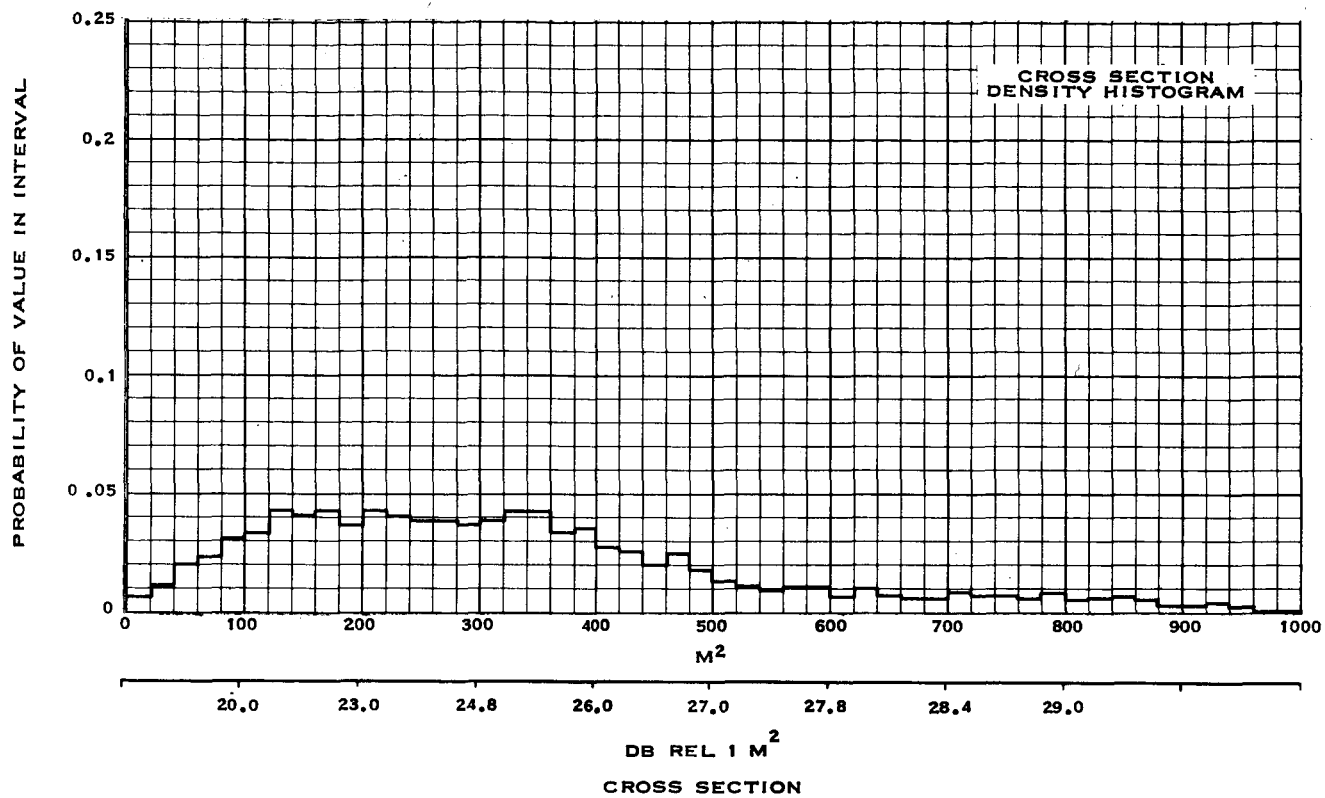


Figure 31. Pass No. 4942 Data (Sheet 2 of 2)

PASS NO. 4965

PASS DATE 20 SEPTEMBER 1961

MONOSTATIC DATA

MEAN CROSS SECTION = 229.92 M²
23.62 DB REL ONE M²

MEDIAN CROSS SECTION = 224 M²
23.5 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 110.43 M²

LOWER DEVIATION FROM MEAN = 88.271 M²

SKEWNESS = 1.25

NO. OF DATA SAMPLES = 3415

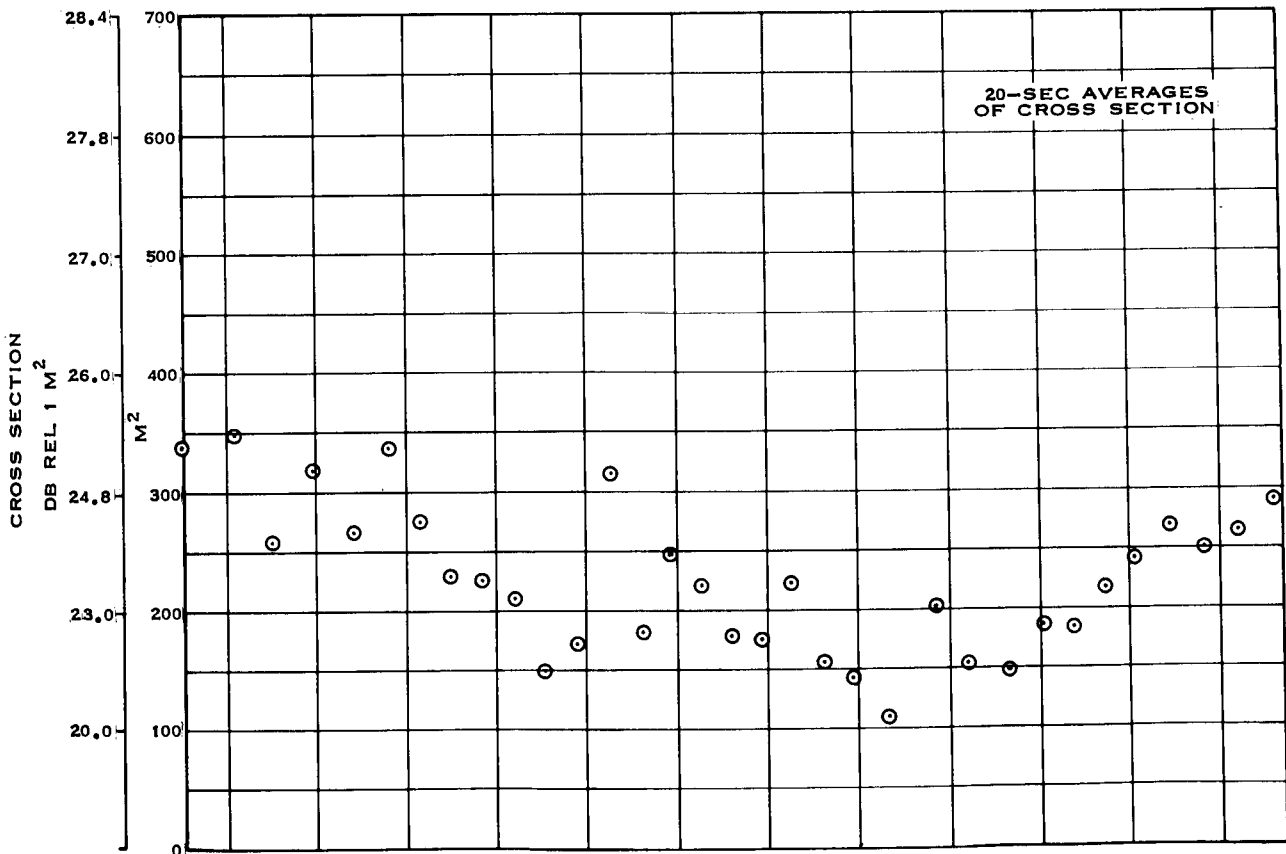
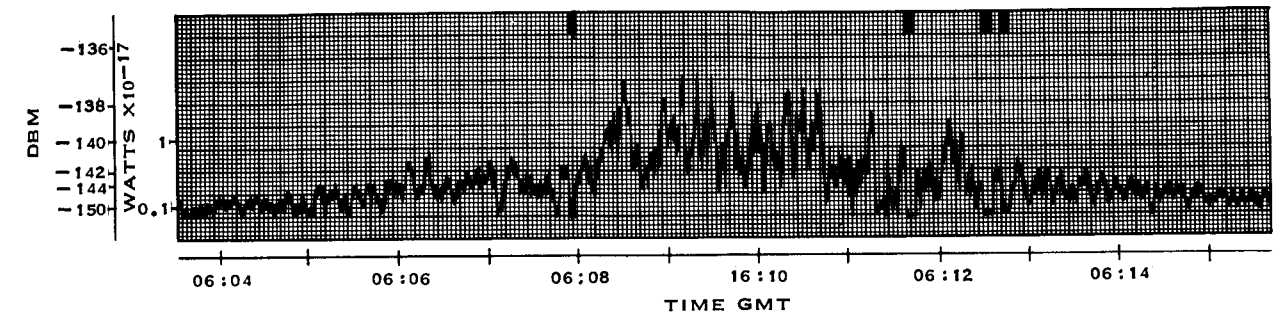


Figure 32. Pass No. 4965 Data (Sheet 1 of 2)

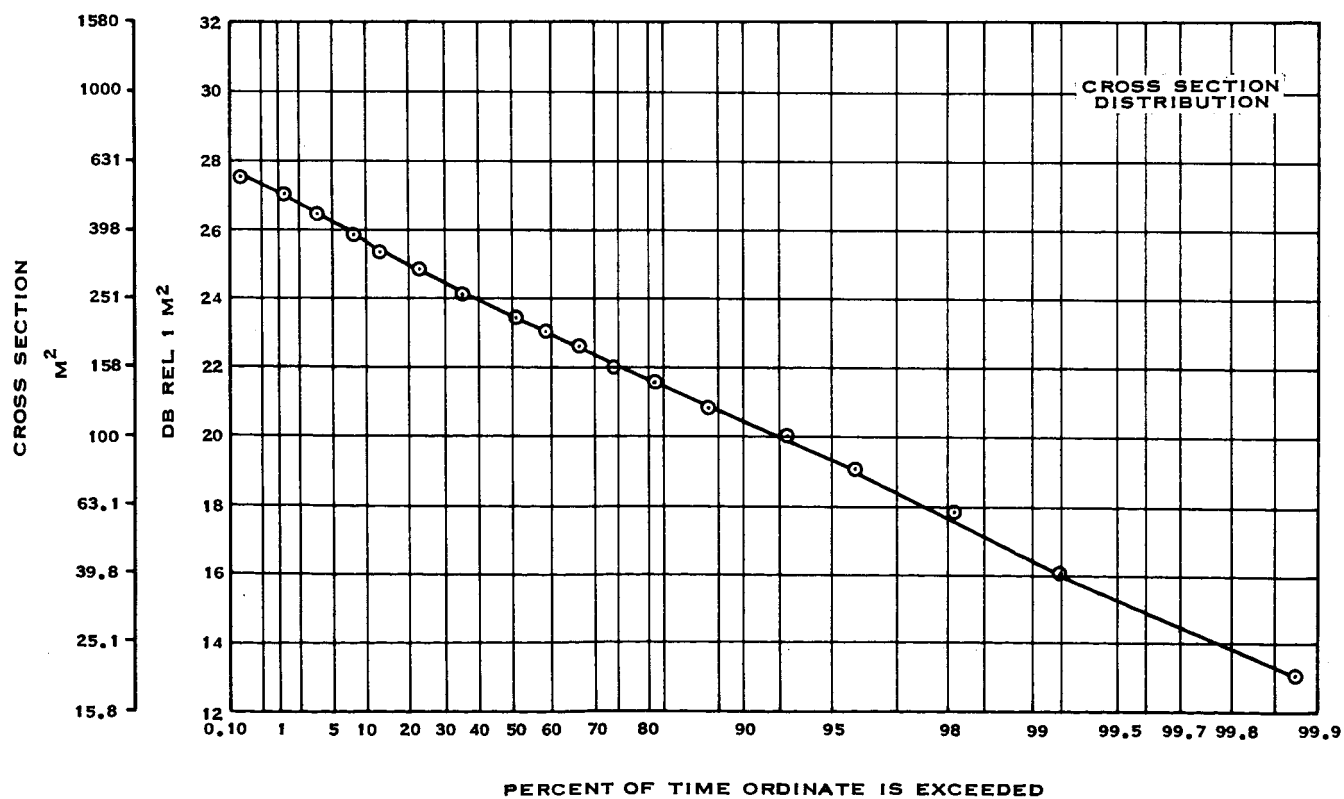
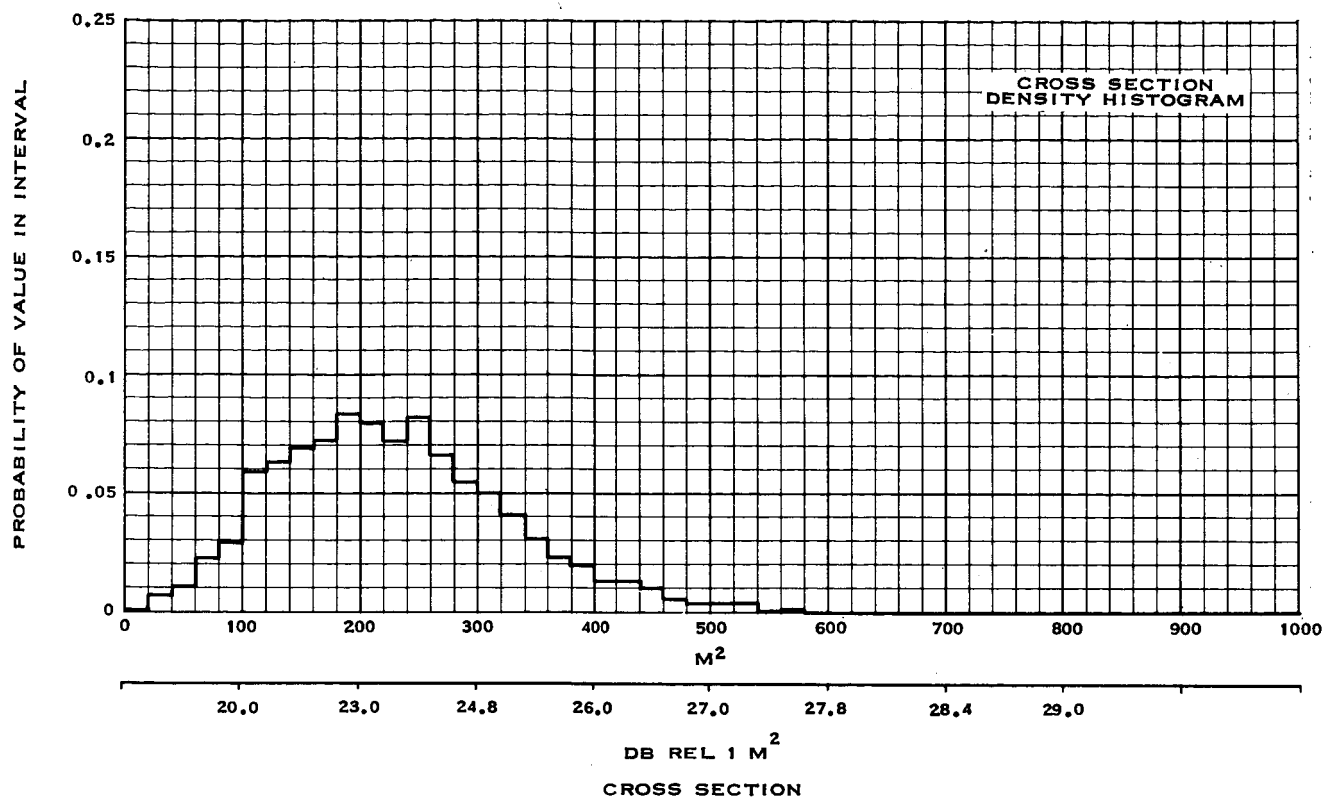


Figure 32. Pass No. 4965 Data (Sheet 2 of 2)

PASS NO. 11299

PASS DATE 12 FEBRUARY 1963

MONOSTATIC

MEAN CROSS SECTION = 124.36 M²
20.95 DB REL ONE M²

MEDIAN CROSS SECTION = 115 M²
20.6 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 82.264 M²

LOWER DEVIATION FROM MEAN = 57.063 M²

SKEWNESS = 1.44

NO. OF DATA SAMPLES = 2339

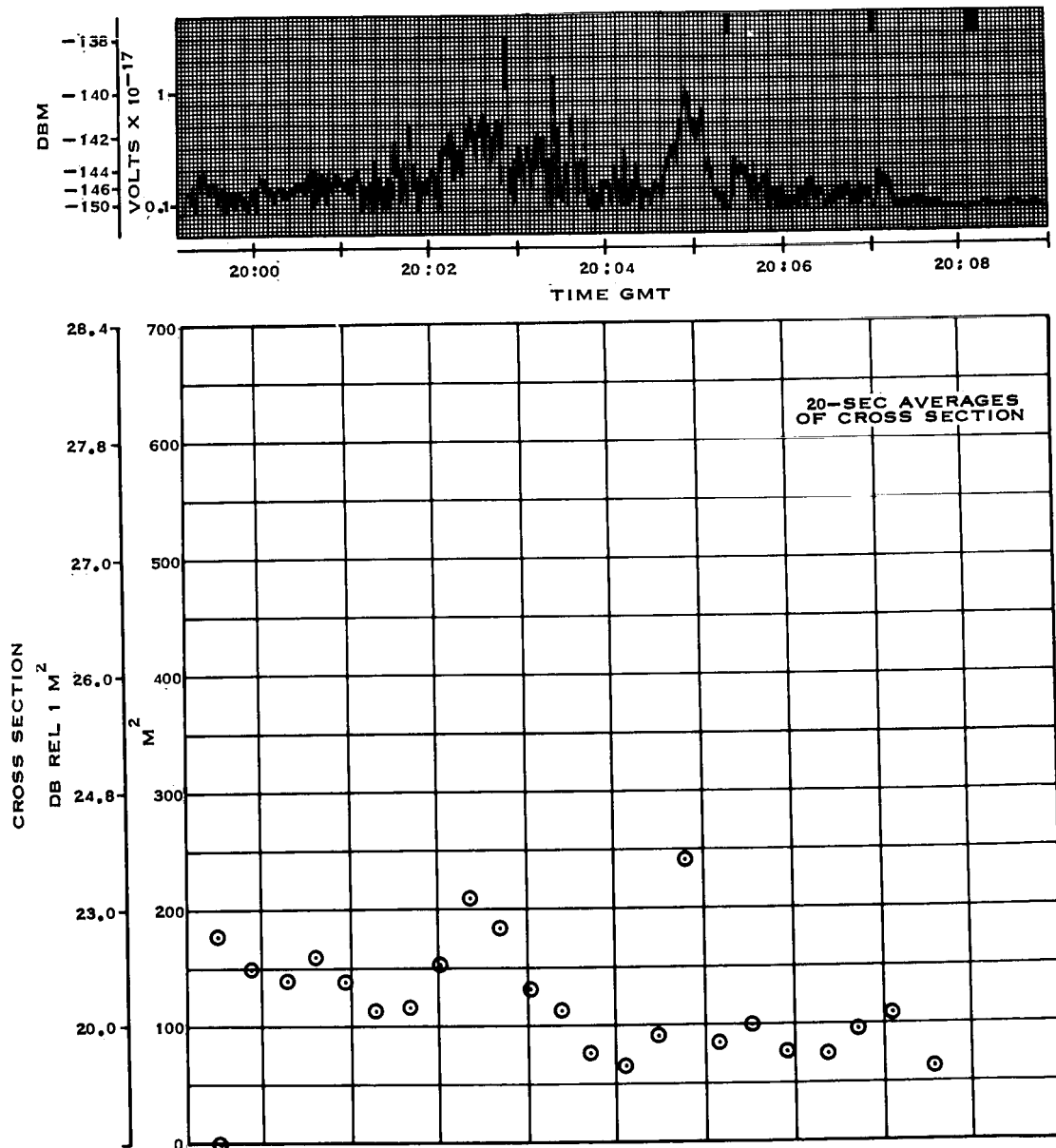


Figure 33. Pass No. 11299 Data (Sheet 1 of 2)

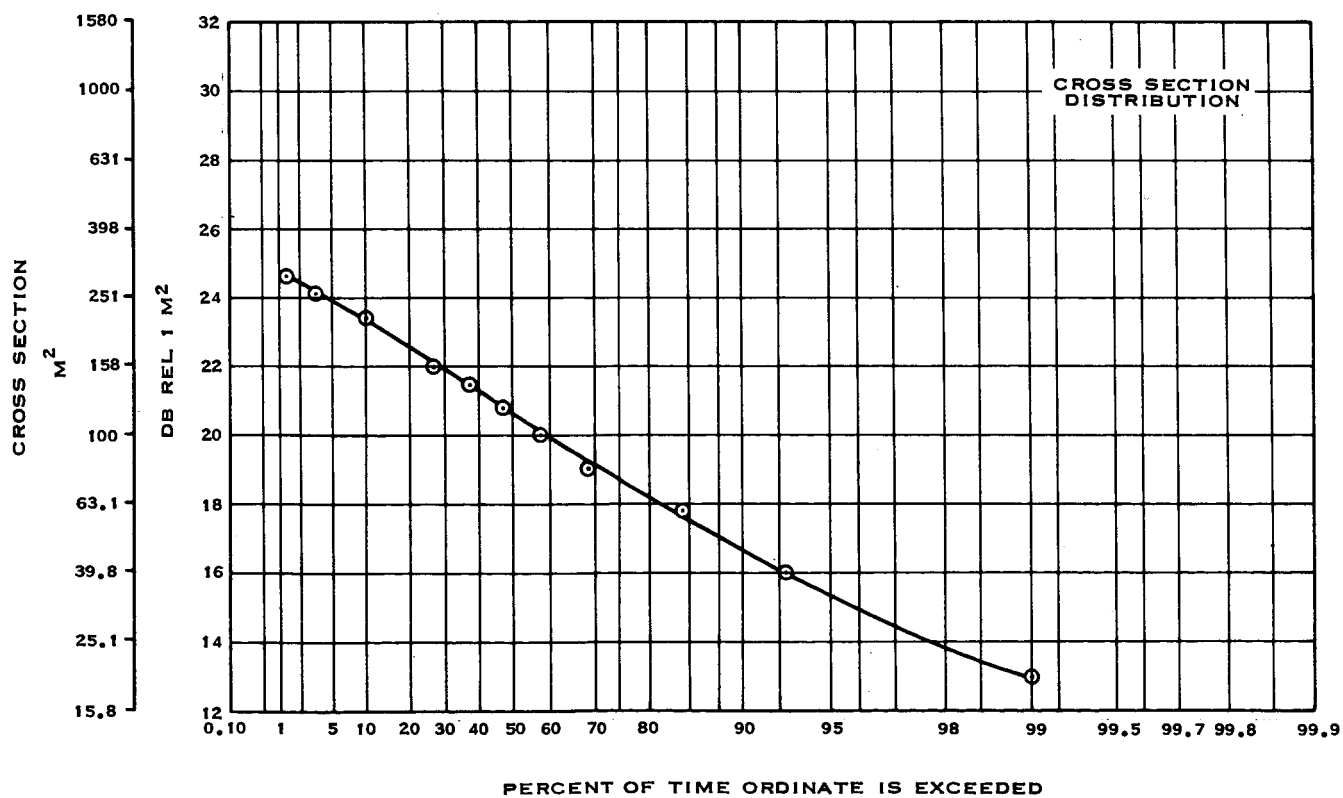
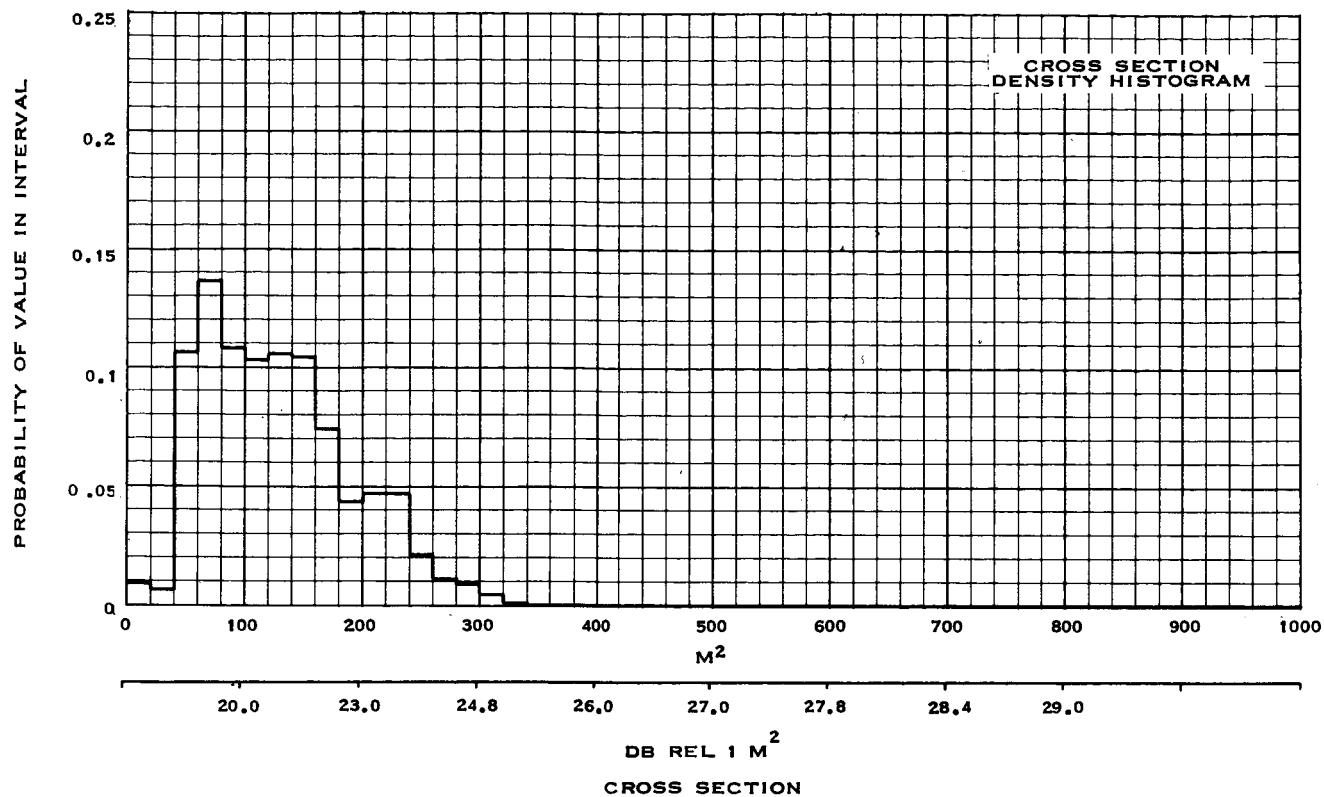


Figure 33. Pass No. 11299 Data (Sheet 2 of 2)

PASS NO. 12115

PASS DATE 19 APRIL 1963

MONOSTATIC DATA

MEAN CROSS SECTION = 220.99 M^2
23.44 DB REL ONE M^2

MEDIAN CROSS SECTION = 199 M^2
23.0 DB REL ONE M^2

UPPER DEVIATION FROM MEAN = 151.39 M^2

LOWER DEVIATION FROM MEAN = 93.587 M^2

SKEWNESS = 1.62

NO. OF DATA SAMPLES = 2352

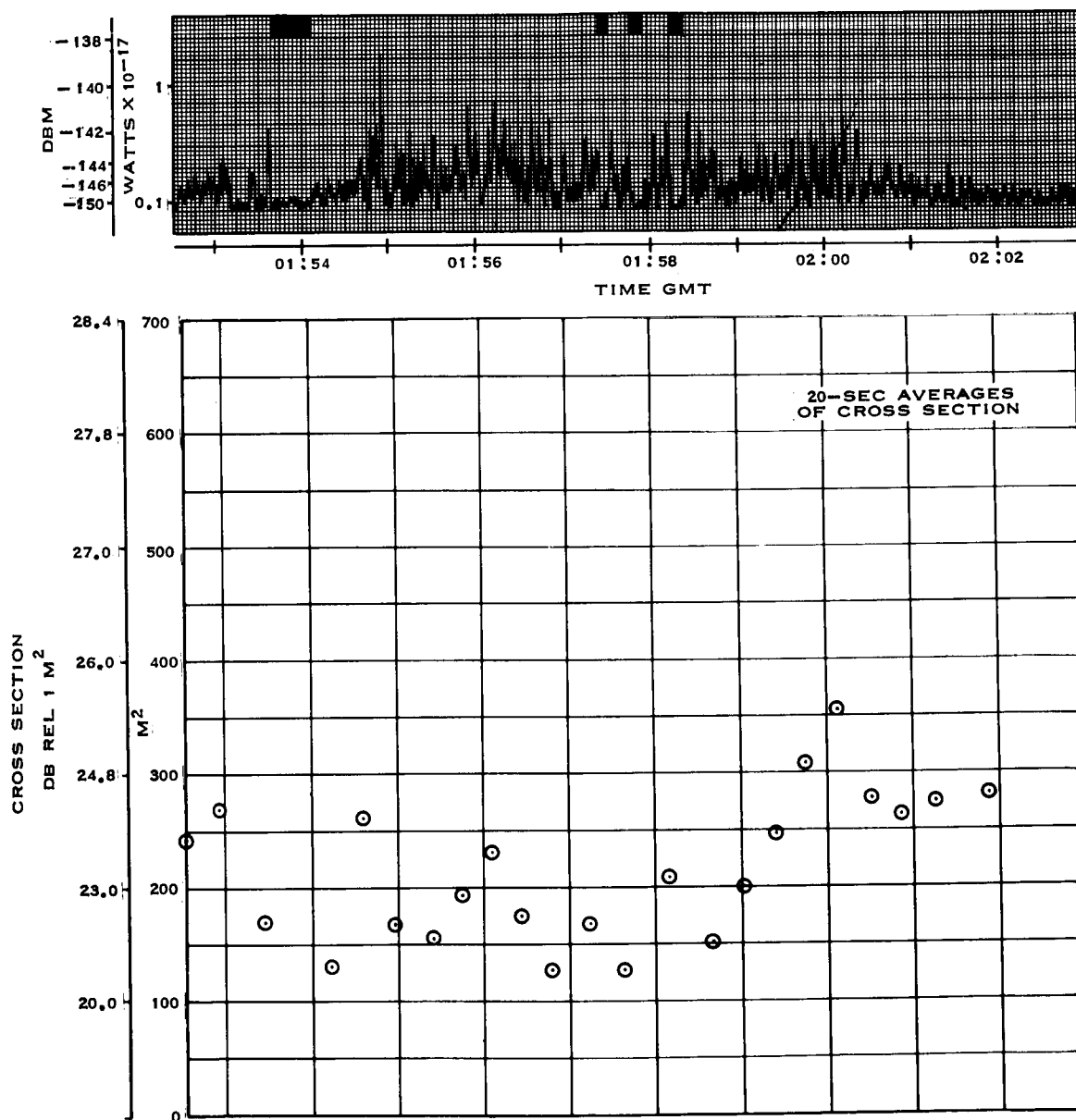


Figure 34. Pass No. 12115 Data (Sheet 1 of 2)

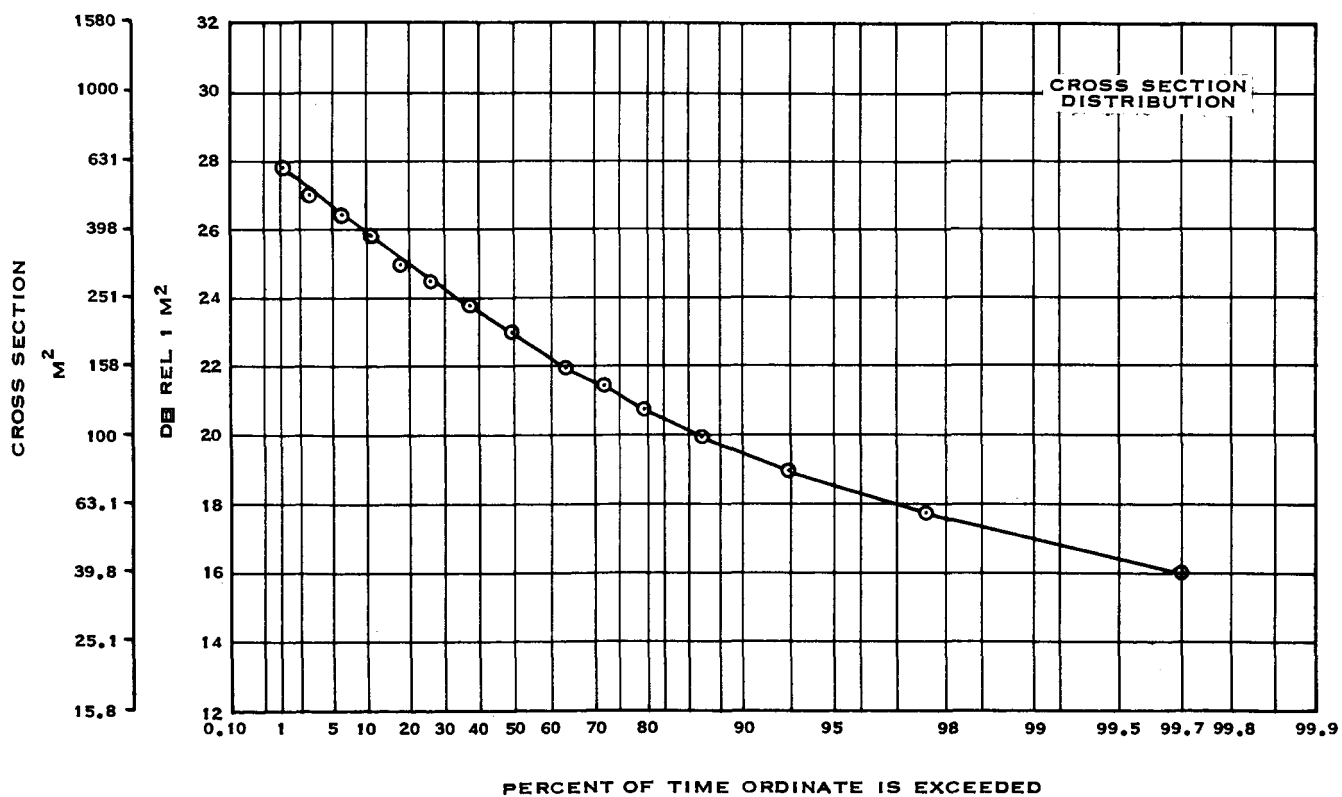
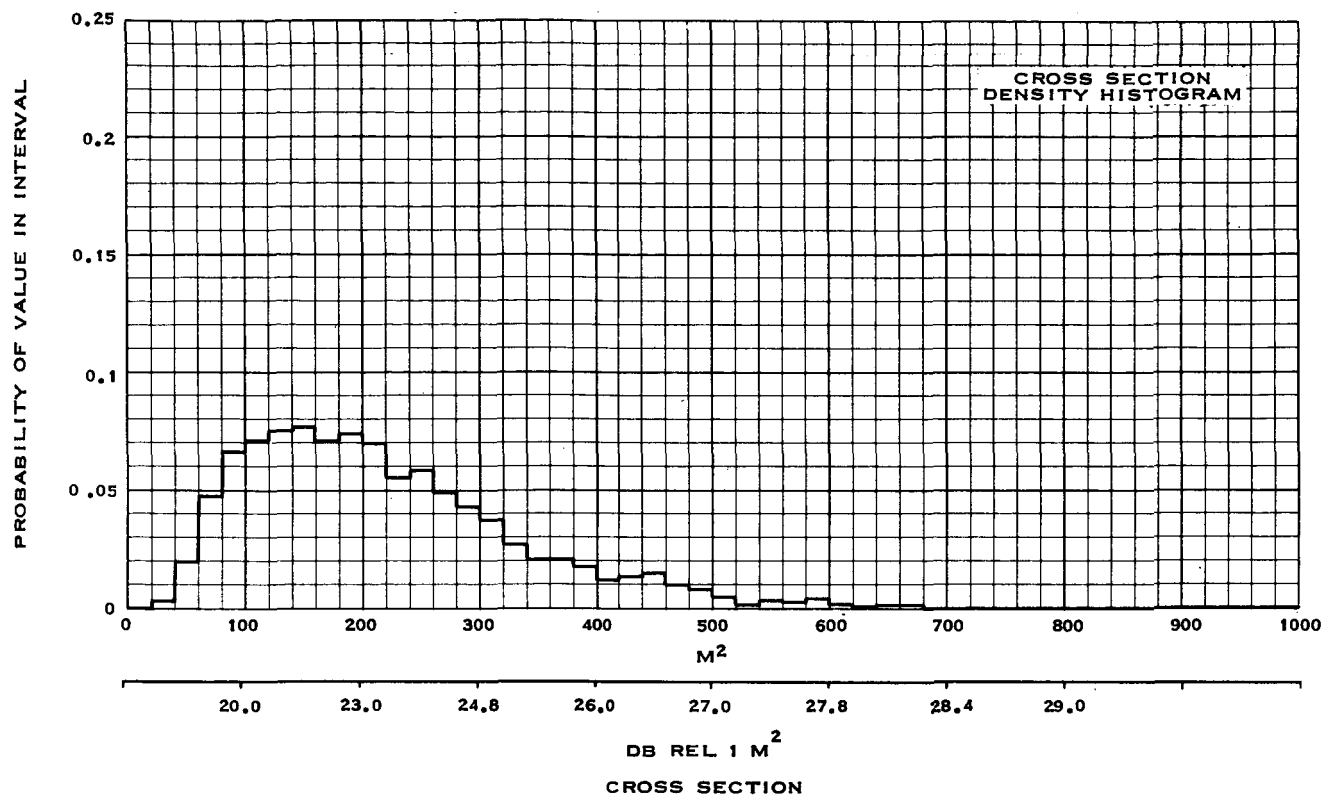


Figure 34. Pass No. 12115 Data (Sheet 2 of 2)

PASS NO. 12127

PASS DATE 20 APRIL 1963

MONOSTATIC DATA

MEAN CROSS SECTION = 122.61 M²
20.90 DB REL ONE M²

MEDIAN CROSS SECTION = 85.1 M²
19.3 DB REL ONE M²

UPPER DEVIATION FROM MEAN = 177.06 M²

LOWER DEVIATION FROM MEAN = 66.851 M²

SKEWNESS = 2.65

NO. OF DATA SAMPLES = 2388

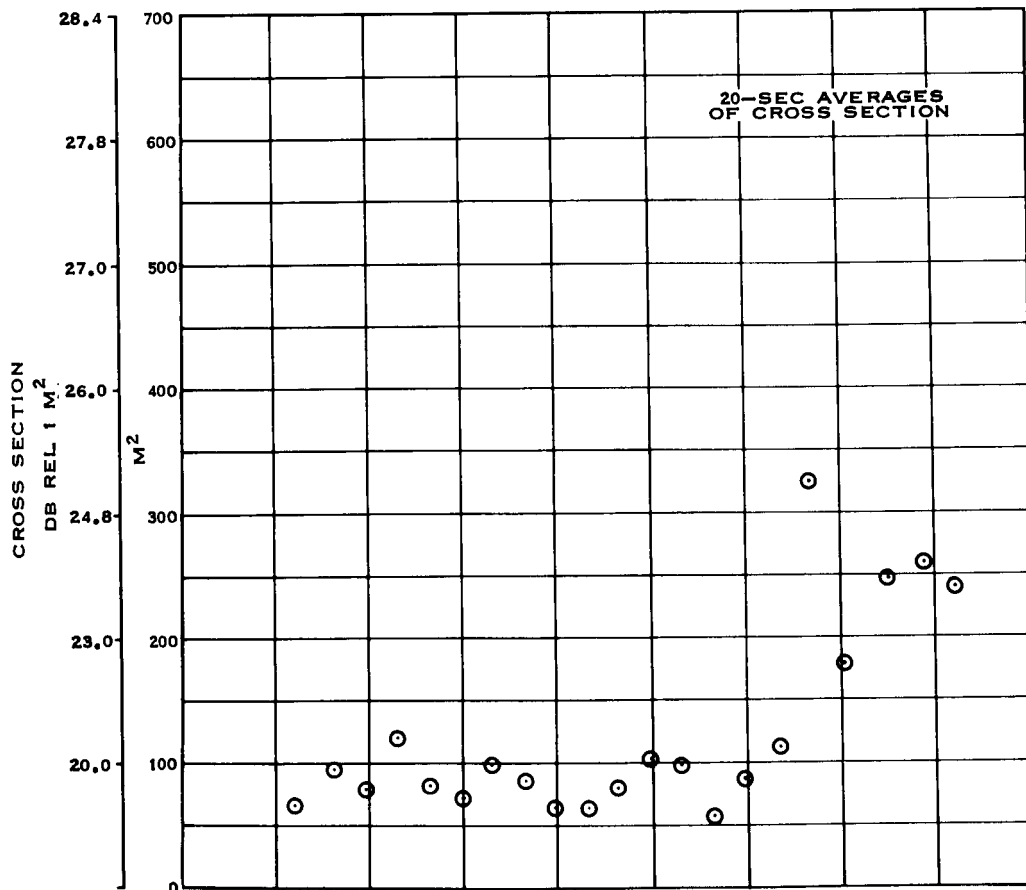
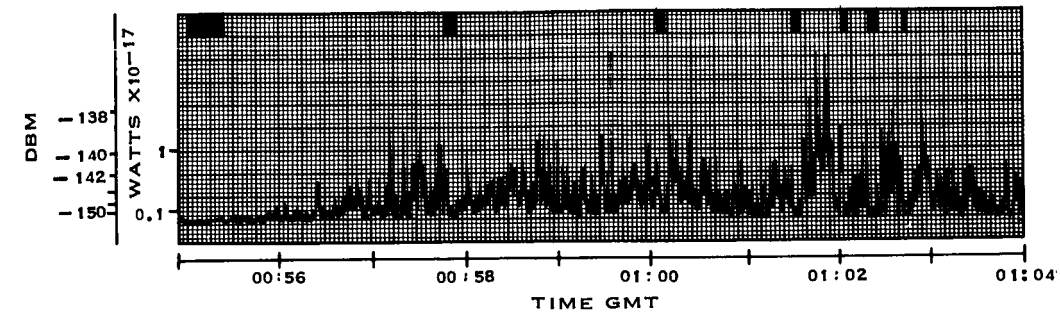


Figure 35. Pass No. 12127 (Sheet 1 of 2)

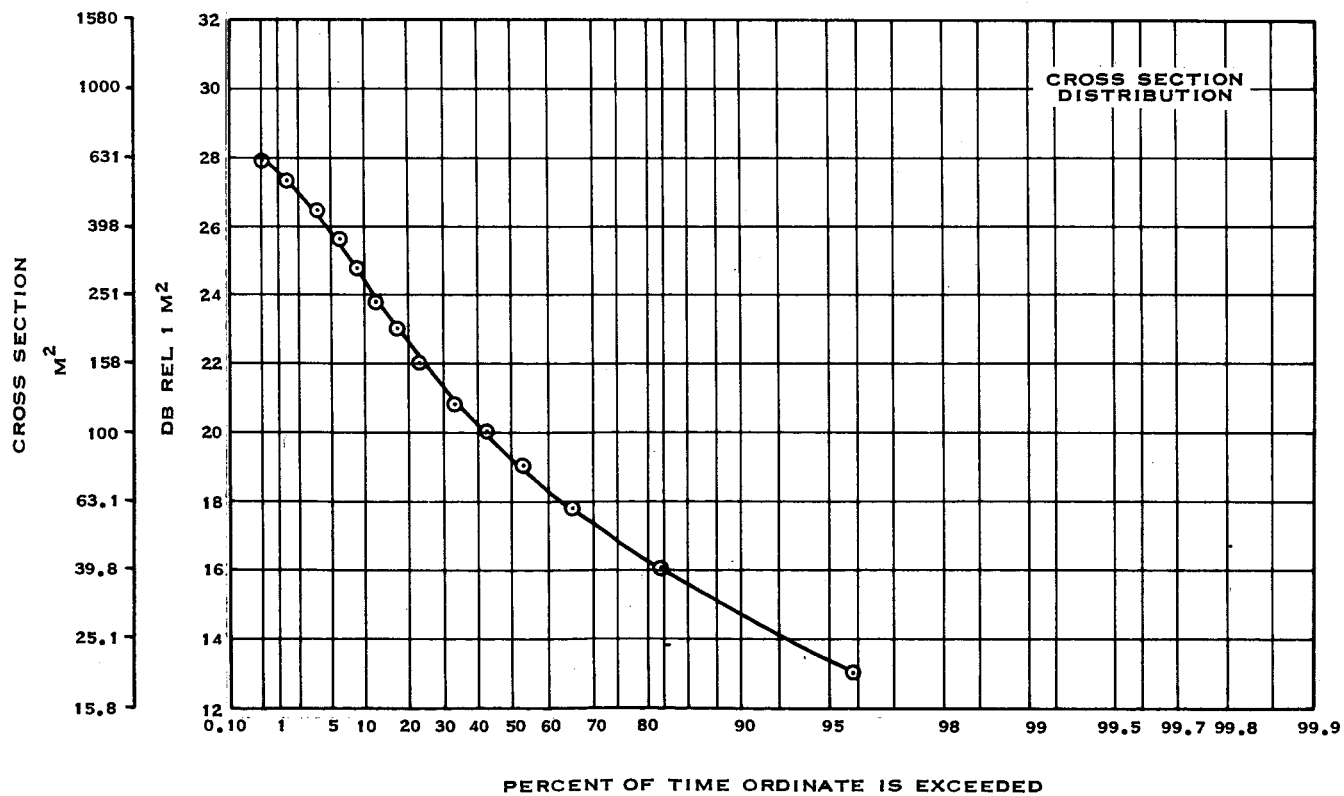
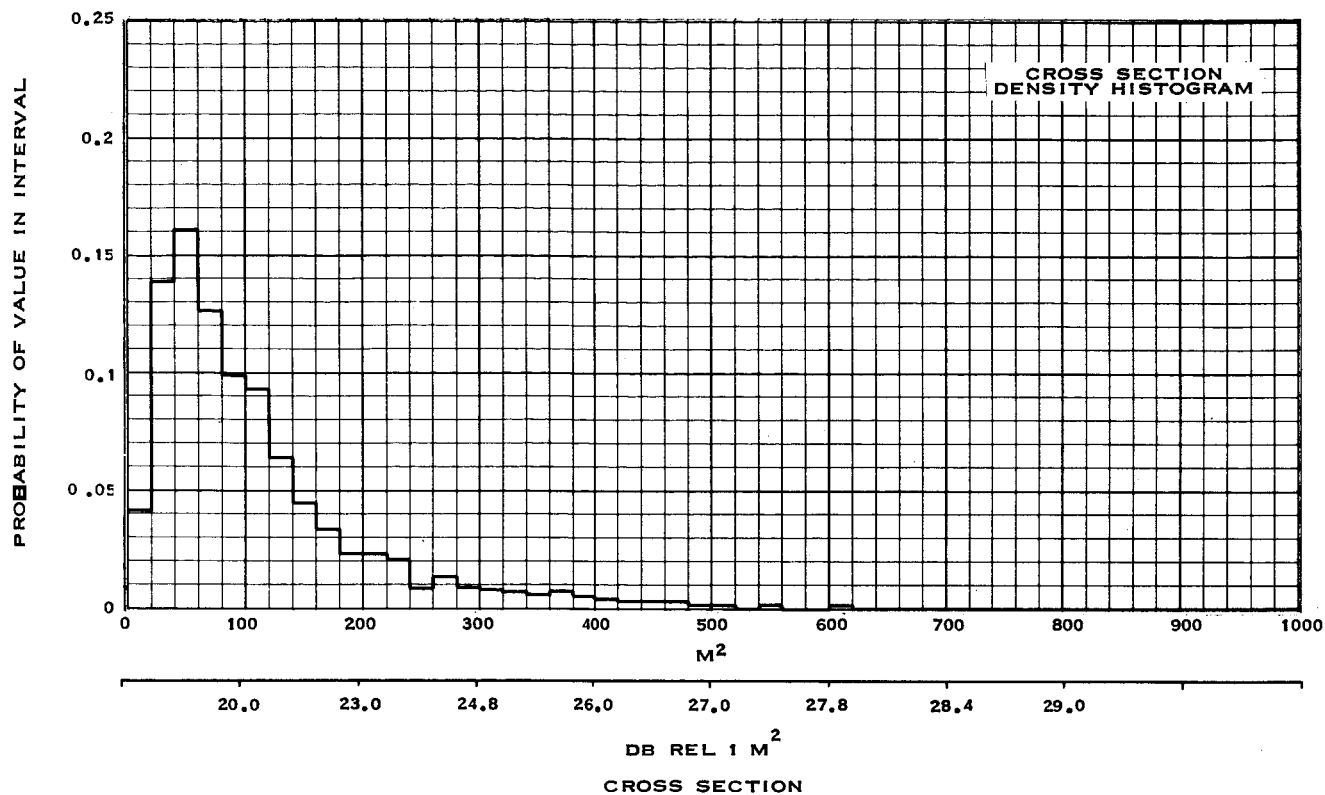


Figure 35. Pass No. 12127 (Sheet 2 of 2)

SECTION 6

CONCLUSIONS

6.1 QUALIFICATION OF RESULTS.

Examination of all available logs, records, and calibrations connected with the data reduced on this program indicates that the raw data was accurate to within the performance of the data-gathering equipment and that error introduced in the data reduction process was very slight. The equipment calibration accuracy can be placed at within ± 2 db, and the accuracy of the data reduction is within ± 1 percent. One exception to the above is the data from pass 84. It is suspected that unscheduled modulation may have been used during the bistatic tracking of this pass. Due to the uncertainty of the absolute magnitude of the satellite cross section as determined from data from this pass, the reduced data from pass 84 was excluded from data comparisons involving absolute cross-section magnitude.

The plots of 20-second averages of effective radio cross section versus time for eight of the 24 passes exhibited an unusual downward convexity during the pass. Curves of cross section versus time obtained from the 20-second averages plots are shown in figure 36 for the eight passes. The time axis is labeled relative to the start of the data samples for each pass. Careful examination of calibration and tracking data for these passes failed to give any clues to the possible causes of this unusual behavior. The same cross-section behavior was observed in the 20-second averages plot for pass 16983 tracked and reduced during the 1964 Echo II program. Since this behavior is apparently not due to anomalies in the data collection and reduction functions, it must be attributable to the actual behavior of the satellite. It is quite probable that this effect is a function of the aspect of the satellite with respect to the tracking stations; however, insufficient data were available to verify this theory.

6.2 HISTORICAL EVALUATION OF ECHO I.

The data from the 24 passes reduced cover the period from 3 days after launch to 32 months from launch. The early life of the satellite was given heavy coverage with 17 passes selected during the first month after launch. The remaining seven passes were distributed over the remaining time. The selection of passes was partially influenced by the availability of suitable data. Thirty passes were originally selected for reduction with six passes being eliminated after more thorough evaluation of tracking operations.

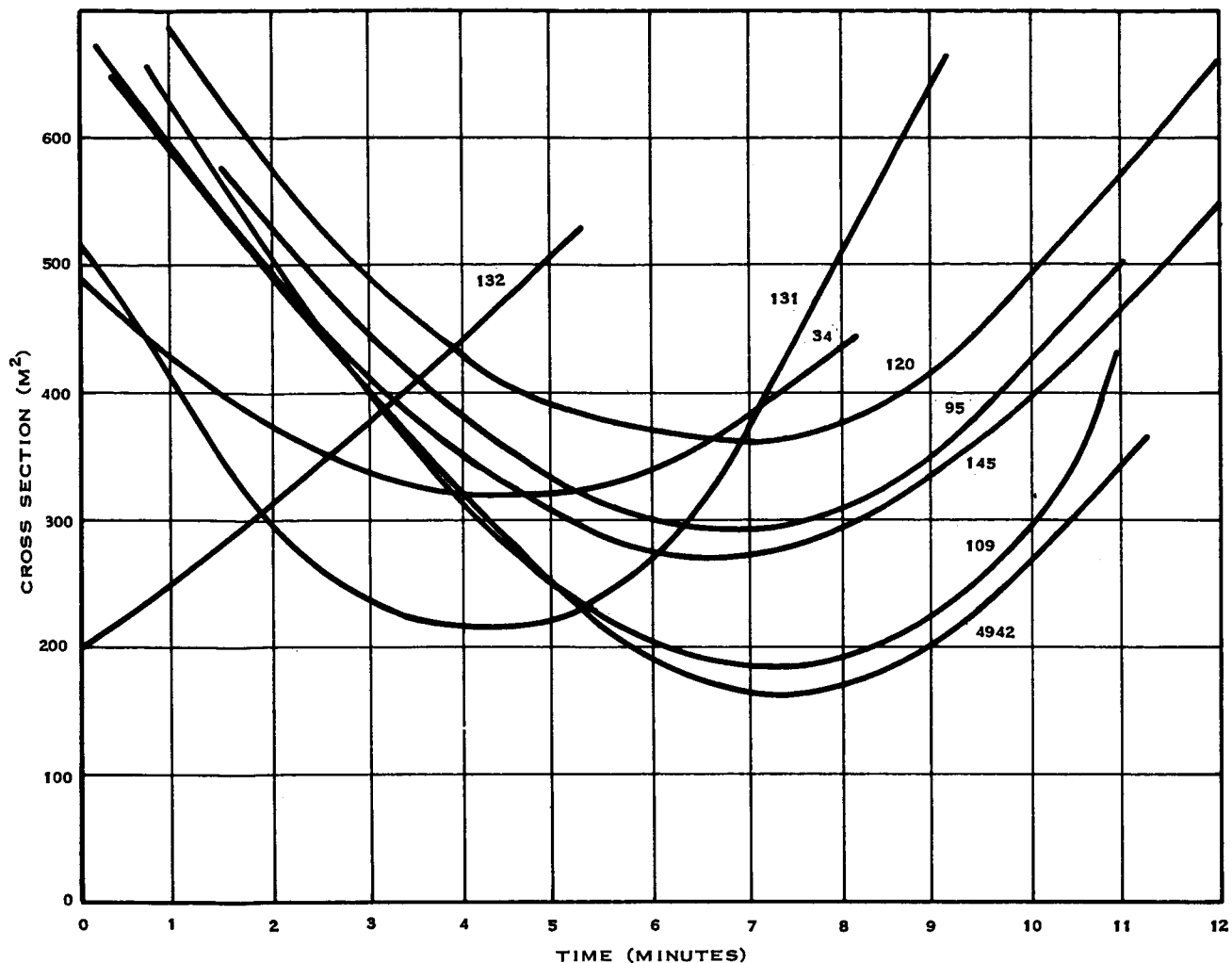


Figure 36. Twenty-Second Averages of Effective Radio Cross Section for Passes 34, 95, 109, 120, 131, 132, 145, and 4942 Exhibiting Unusual Changes in Cross Section

The mean, median, upper and lower deviations, and skewness for each pass are listed in table 1. The mean and median cross-section values are generally very nearly the same with the median usually falling below the mean. The skewness (ratio of upper to lower deviation) is generally close to unity with a slight tendency toward higher values with later passes. Plots of satellite cross section per pass versus time are shown in figure 37 for values in square meters and in db relative to one square meter. This plot shows that the mean cross section was about 3 db below the theoretical cross section during the first month after launch and gradually dropped to about 6 db below theoretical during the following 3 years.

TABLE 1. MEAN, MEDIAN, UPPER DEVIATION, LOWER DEVIATION
AND SKEWNESS FOR EACH OF 24 PASSES

PASS NO.	DATE	MEAN		MEDIAN		UPPER DEVIATION M ²	LOWER DEVIATION M ²	SKEWNESS
		M ²	DB	M ²	DB			
34	8-15-60	359.83	25.56	347	25.4	119.99	67.863	1.78
47	8-16-60	311.48	24.93	324	25.1	108.08	128.42	0.84
57	8-17-60	336.15	25.26	363	25.6	66.213	121.72	0.55
72	8-18-60	271.01	24.33	269	24.3	54.581	57.684	0.95
84	8-19-60	51.677	17.12	50.1	17.0	16.449	12.460	1.32
95	8-20-60	400.64	26.04	390	25.9	149.74	129.04	1.16
96	8-20-60	551.49	27.41	575	27.6	101.63	184.25	0.55
109	8-21-60	381.87	25.82	295	24.7	292.38	171.66	1.70
120	8-22-60	460.60	26.64	437	26.4	182.33	141.12	1.30
131	8-23-60	415.28	26.18	331	25.2	286.98	159.71	1.80
132	8-23-60	351.35	25.45	339	25.3	139.70	116.11	1.20
143	8-24-60	247.89	23.94	246	23.9	61.533	54.701	1.13
145	8-24-60	400.68	26.04	355	25.5	194.81	102.32	1.90
168	8-26-60	179.38	22.54	174	22.4	68.222	44.418	1.54
180	8-27-60	467.85	26.70	457	26.6	140.27	119.29	1.18
240	9-1-60	239.24	23.78	229	23.6	86.882	67.669	1.28
325	9-8-60	349.51	25.44	331	25.2	139.11	102.61	1.36
2483	3-3-61	112.46	20.47	95.5	19.8	107.91	46.217	2.33
4368	8-3-61	349.98	25.44	309	24.9	239.06	156.50	1.52
4942	9-18-61	335.49	25.25	295	24.7	257.69	167.00	1.54
4965	9-20-61	229.92	23.62	224	23.5	110.43	88.271	1.25
11299	2-12-63	124.36	20.95	115	20.6	82.264	57.063	1.44
12115	4-19-63	220.99	23.44	199	23.0	151.39	93.587	1.62
12127	4-20-63	122.61	20.90	85.1	19.3	177.06	66.851	2.65

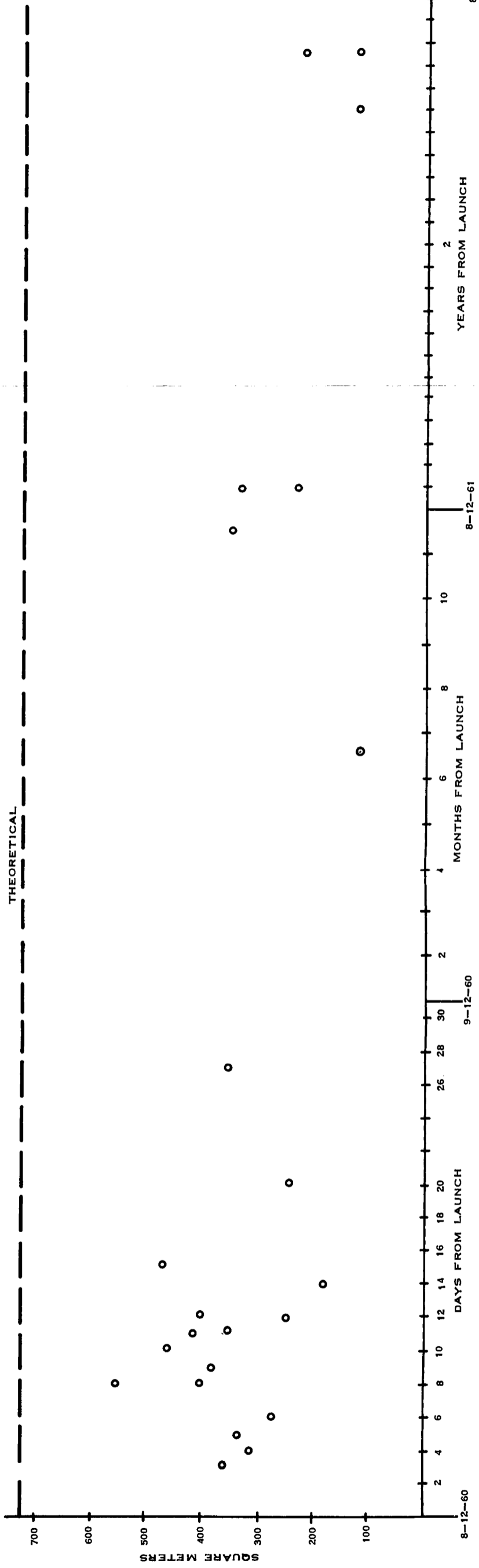
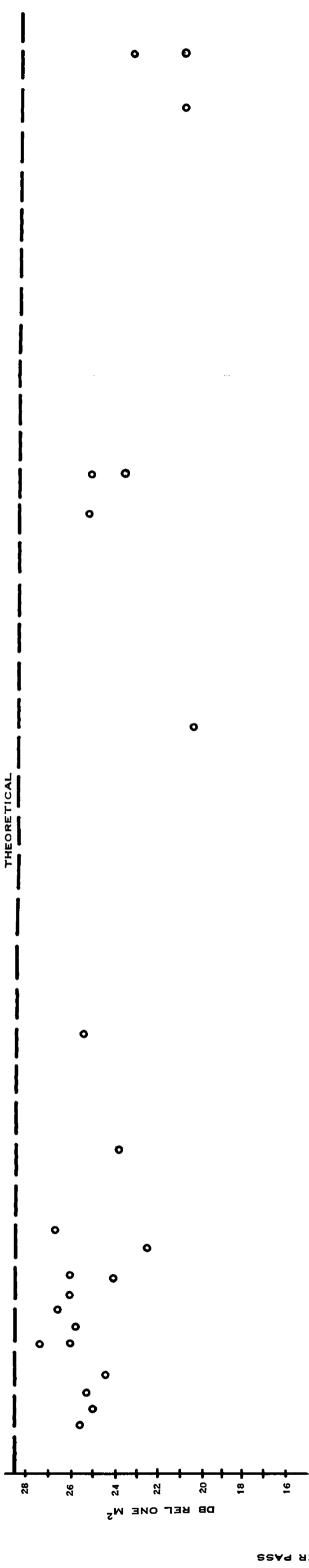


Figure 37. Mean Cross Section per Pass Versus Time from Launch

The cross-section distributions for eight passes are shown in figure 38 plotted relative to their respective median values. The passes were selected for quality of data and distribution in time. An indication of the depth of cross-section fading can be obtained from the distribution curves, for example, the steeper the distribution, the wider the range of scintillation. Figure 38 shows that the cross-section scintillation was of quite small magnitude during the early life of the satellite with a slight increase during 3 years from launch. A number commonly used to indicate the range of signal variation is the 10 to 90 percent fade range (the difference between the value exceeded 10 percent of the time and the value exceeded 90 percent of the time). During the first month from launch the 10 to 90 percent fade range was typically 2 to 4 db. This quantity gradually increased to about 6 to 8 db over 3 years time.

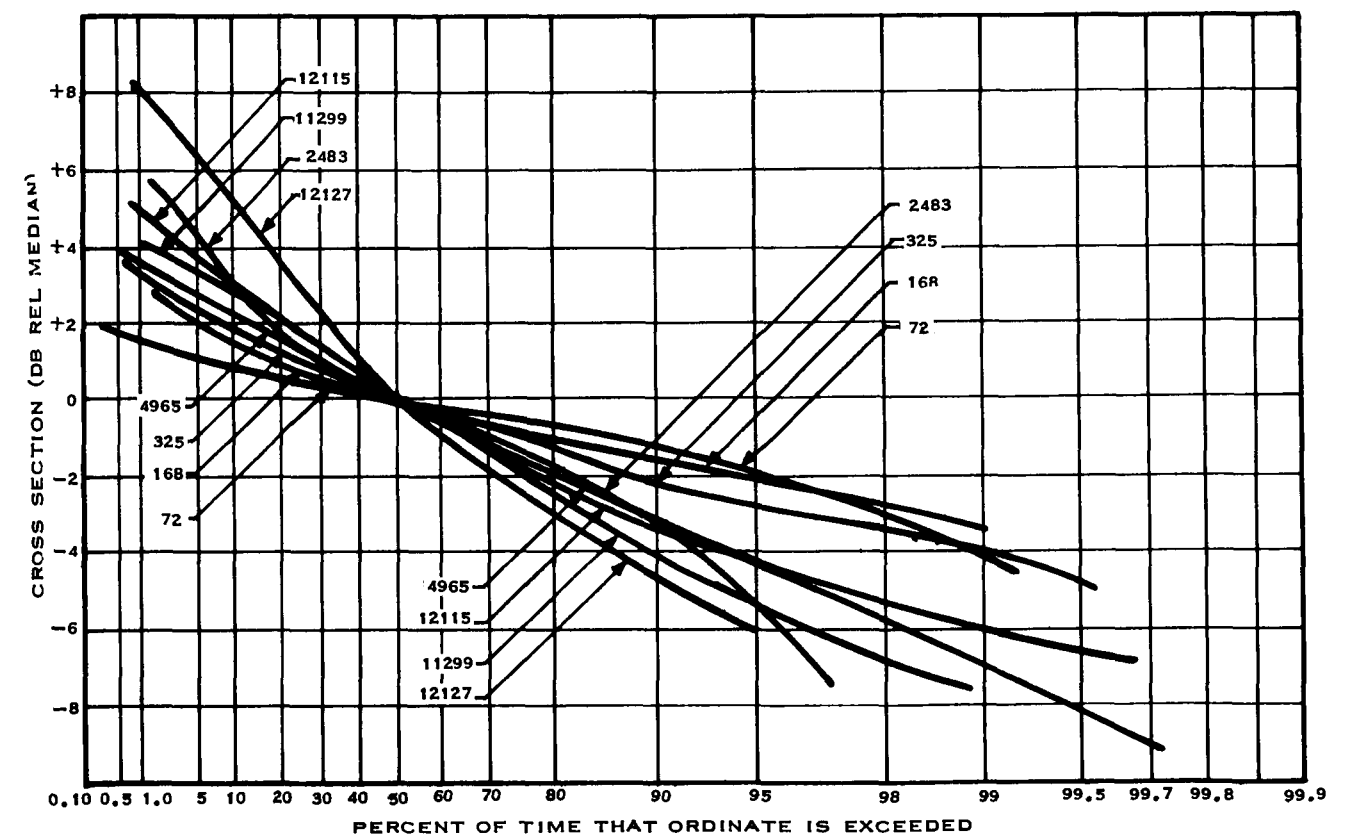


Figure 38. Distribution of Cross Section in DB Relative to the Median Cross Section for Passes 72, 168, 325, 2483, 4965, 11299, 12115, and 12127

First eclipse of the Echo I satellite by earth shadowing occurred about 12 days after launch (pass 146 on August 24). The first observation following this event for which data was reduced was for pass 168 on August 28 which was not shadowed. Subsequent passes observed were not shadowed. No significant trends toward changes in amplitude density, distribution, mean or median cross section can be associated with this event from these data. Significant changes were observed during the intervals while the satellite was actually shadowed which were reported,⁶ but these effects did not appear to have produced significant or permanent changes in subsequent data during nonshadowed periods.

6.3 COMPARISON OF ECHO I AND ECHO II.

The comparison of Echo I and Echo II is based on Echo I data contained in sections 5 and 6 of this report and Echo II data reported.^{7 8} Data in this report were taken at 810 MHz and in references 7 and 8, at frequencies near 2.3 GHz. The first comparison is made during the period of the first year of life for each satellite. Table 2 was prepared for this purpose.

TABLE 2. A COMPARISON OF THE CHARACTERISTICS FOR ECHO I AND ECHO II DURING THEIR FIRST YEAR LIFE PERIOD

CHARACTERISTIC	ECHO I MEASURED AT 810 MHz	ECHO II MEASURED AT 2.3 GHz
Theoretical cross section	729.64 m ² or 28.63 db rel m ²	1329.81 m ² or ₂ 31.23 db rel m ²
Average measured mean cross section	343.70 m ² or 25.36 db rel m ²	1050 m ² or 30.2 db rel m ²
Difference between average measured mean and theoretical cross section	53.0 percent or 3.27 db	26.8 percent or 1.0 db
Average measured median cross section	321.0 m ² or 25.1 db relative to m ²	719.0 m ² or 28.6 db relative to m ²
Difference between average measured median and theoretical cross section	44 percent or 3.53 db	54.2 percent or 2.63 db
Range of skewness about the mean cross section	0.55 to 1.90	2.10 to 6.24
Typical 10 to 90 percent fading range	4 db	13 db

During the first year period of life, the ratio for Echo I of the averaged measured mean cross section to the theoretical value was about 2 db less than the same measured-to-theoretical relation for Echo II; Echo I, about 3 db less than theoretical and Echo II, 1.0 db less than theoretical. The same comparison applied to the averaged median cross section showed a difference in ratios of about 1 db; Echo I, 3.5 db less than theoretical and Echo II, 2.6 db less than theoretical. The magnitude of amplitude scintillation appeared less for Echo I than Echo II; the range of skewness of amplitude density was one-fourth to one-third and 9 db less in typical 10 to 90 percent fading range. These latter two comparisons may be somewhat sensitive to wavelength depending upon surface irregularities or resonances. If the surface irregularities are large with respect to wavelength, then the features of the satellite may vary greatly with aspect of the satellite. Such differences between Echo I and Echo II may be possible and may partially account for differences in fading structure exhibited when comparing the recorded signals as function of time (for example, strip chart records) and the statistics of fading.

In references 7 and 8, comparisons are made using data taken at a frequency near 2.3 GHz. These were taken late in the third year and early in the fourth year of life of Echo I and during the first year of life of Echo II. It was observed, from the limited data available, that the amplitude distribution⁷ and the fading characteristics⁸ for Echo I and Echo II are very similar. This conclusion may also be implied from the historical trends shown in paragraph 6.2 of this report. The fading range for Echo I gradually increased over the 3-year period from a typical 10 to 90 percent value of 2 to 4 db to a value of 6 to 8 db. Although it is unsafe to extrapolate a value of fading range into the fourth year from these data, the 11 to 12 db shown⁷ for the data for Echo I may not be unrealistic even if the effect of the wavelength differences for the measurements is ignored. Thus, a second comparison may be made showing the amplitude distribution (and fading range) and the fade duration and fade period distributions for Echo I to be similar to Echo II after three years of life of Echo I. This is contrasted with the differences observed between Echo I and Echo II during their first years of life. However, on a pass-to-pass basis, separate observations show individual and sometimes considerable variations, particularly with respect to the rate of fading.

6.4 COMMUNICATION CAPABILITY.

From the data presented in this report and the referenced documents, it can be concluded that a reasonably stable communication link can be maintained with Echo-type satellites. In all cases it appears that the path loss is slightly greater than that predicted on the basis of a perfect sphere of the design diameter and that the signal level varies in a random

manner as if the sphere were very rough. The Echo I satellite appeared relatively smooth early in its life and then appeared to become rough. Diminution of cross section with time was not excessive for a system with adequate margin at time of launch.

The signal scintillation is a consideration requiring corrective measures but its magnitude is not uncommon in electromagnetic communication systems. Ninety-nine percent of the time the signal is above a level 8 db below the median (see figure 38). A coherent bandwidth (correlation coefficient of >0.5) of approximately 10 to 50 MHz can be expected with this type of satellite based on data taken on Echo II^{1 6} which can be reasonably applied to Echo I. Frequency diversity and time diversity are obvious and effective solutions to this type of fading environment and should be considered when designing systems. Specific system design must be tailored for a satellite reflector of this type for obtaining desired communication channel characteristics. The parameters, herein computed, when utilized, will enable a system designer to make the proper engineering trade-off decisions. The fading analysis of the Echo I signal data would be of additional value for specific design considerations. The limited fading data for Echo I provided⁸ and the changes historically in the effective radio cross section and amplitude density and distribution provide a basis for estimating expected values for fade duration and periods.

6.5 SUMMARY OF CONCLUSIONS.

1. The averaged mean effective radio cross section was about 3 db below the theoretical value during the first month after launch gradually dropping over nearly three years to about 6 db below theoretical.

2. Mean and median values of the effective radio cross section are very nearly the same with the median frequently falling just below the mean.

3. The 10 to 90 percent fade range changed gradually from the typical range of 2 to 4 db during the first month to 6 to 8 db near the end of the third year.

4. Plots of 20-second averages of effective radio cross section versus time for eight of 24 passes analyzed exhibited unusual downward convexities. This anomalous behavior appears to be a function of the aspect of the satellite with respect to the ground stations.

5. Effects observed when the satellite was shadowed did not appear to have produced permanent changes in the amplitude densities, distributions, means or medians during the nonshadowed periods to follow.

6. During the first year of life for both Echo I and Echo II satellites, the averaged mean cross section for Echo I was about 3 db below the theoretical value and for Echo II was 1.0 db below the theoretical value. The averaged median cross section for Echo I was about 3.5 db below theoretical and for Echo II, about 2.6 db below theoretical.

7. The range of skewness in the amplitude density functions for Echo I appeared to be one-fourth to one-third of those for Echo II and 9 db less in typical 10 to 90 percent fading range during the first year life periods for each satellite.

8. The similarities in amplitude distribution and fade period and duration characteristics cited in the data measured at about 2.3 GHz ^{7 8} are largely confirmed by the gradual increase of the typical 10 to 90 percent fade range data obtained in this analysis.

9. The signal scintillation encountered does not require uncommon corrective measures; 99 percent of the time the signal was no more than 8 db below signal median.

REFERENCES

1. Collins Radio Company, "Final Report for The Collins Radio Company and Alpha Corporation participation in Project Echo," Collins Research Report 234, 1961.
2. Bergemann, G. T., and Beamer, C. M., "An Experimental Communications Circuit Utilizing Echo I," Collins Research Report 264, 1962.
3. Sharf, A. R., Collins, Richardson, Texas, "Satellite Tracking and Communication Facility," Collins Research and Development Publication 175, 1963.
4. Beamer, C. M., and Bergemann, G. T., "Collins Radio Company Communication Research Facility," Collins Research Report 247, 1961.
5. Weis, V. A., "Receiver Description for the Communication Research Facility," Collins Research Report 250, Volumes I and II, 1961.
6. Jakes, W. C., Jr., "Participation of Bell Telephone Laboratories in Project Echo and Experimental Results," B.S.T.J., Volume XL, No. 4, 1961.
7. Collins Radio Company, "Echo II Experimental Program Final Report," Contract NAS 5-3640, 1965.
8. Collins Radio Company, "Final Report for Signal Fading Characteristics, Echo II," Contract NAS 5-9648, 1966.